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**ALTITUDE TEST OF THE AEROJET MODIFIED
HEAVYWEIGHT FULL-SCALE CONTROLLABLE
SOLID-PROPELLANT ROCKET MOTOR
(CSRM-4)**

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ENGINE TEST FACILITY
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November 1973

Final Report for Test Conducted June 25, 1973

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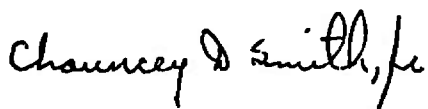
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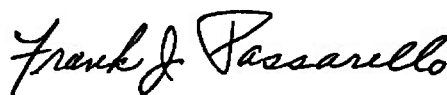
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>The Aerojet Solid Propulsion Company modified, full-scale, heavyweight, Controllable Solid Rocket Motor (CSRM-4), was successfully test fired at simulated pressure altitude in Rocket Development Test Cell J-5 of the Engine Test Facility, AEDC, on June 25, 1973. The primary test objective, propellant extinguishment, was demonstrated on five repetitive programmed firings; the five 5-sec duration firings were separated by 60-sec extinguished</p> | | |

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coast periods. Motor chamber pressure at propellant extinguishment was 36, 26, 32, 30, and 26 psia for the five firings. Postfire condition of the motor was satisfactory.

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PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), and was sponsored by the Advanced Ballistic Missile Defense Agency (ABMDA), U.S. Army, for the Aerojet Solid Propulsion Company (ASPC), a division of Aerojet General Corporation under Program Element 921C-1. The results of the test presented herein were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in Rocket Development Test Cell (J-5) of the Engine Test Facility on June 25, 1973, under Project No. RA207, and the manuscript was submitted for publication on September 20, 1973.

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1.0 INTRODUCTION

The ASPC Controllable Solid Rocket Motor (CSRM) is a research and development motor which is being developed to define the technology required for a variable thrust, extinguishable, multiple restart, solid-propellant rocket motor. The CSRM utilizes a high-burn-rate exponent propellant and a variable throat area nozzle to control motor chamber pressure, thereby thrust, and provide for propellant extinguishment.

Two full-scale, heavyweight CSRM's have been previously test fired by ASPC at sea-level conditions (Refs. 1 and 2). These firings indicated that the concept was feasible; however, propellant extinguishment could not be demonstrated at sea-level conditions. Two subscale (and one full-scale) CSRM's were subsequently fired under simulated pressure altitude conditions in Test Cell J-5 (Fig. 1), and the results were reported in Refs. 3, 4 and 5. Variable thrust, thrust vector control, and propellant extinguishment were achieved on the subscale firings. Variable thrust and thrust vector control were demonstrated on the firing of full-scale motor CSRM-3; however, the motor failed to achieve propellant extinguishment.

The test reported herein was for CSRM-4 which was modified based on CSRM-3 test results. Modifications included a return to the propellant formulation used successfully on the two AEDC subscale motor firings, a design alternation in the nozzle geometry, and the removal of an 18-in. cylindrical section of propellant and case from the center of the thrust chamber. Alteration of the nozzle geometry was accomplished to improve the internal aerodynamics of the nozzle system and removal of 18 in. of propellant was accomplished to reduce propellant surface area, thereby improving motor extinguishability. The primary objective of the CSRM-4 test was to demonstrate propellant extinguishment over a range of motor free volumes to provide baseline data for the CSRM system. Five identical repetitive firings were programmed in the following sequence: 400-psia chamber pressure for 3 sec, a step to 86 psia for 2 sec, extinguishment, and a 60-sec extinguished coast period.

2.0 APPARATUS

2.1 TEST ARTICLE

The ASPC modified, full-scale, heavyweight CSRM (Fig. 2) consists of a heavyweight chamber approximately 47 in. in diameter and 98 in. long, containing approximately 6000 lb of ANP-3357-4B propellant in an aft-restricted, forward finocyl, grain configuration. The propellant was fully case-bonded except in the aft boot area. The liner material is

polyurethane SD-902, and the chamber insulation is filled nitrile rubber V-44 (V-45 in the aft boot only). The burn rate exponent (n) for this propellant is 0.91 in the general burn-rate expression:

$$r = aP^n$$

r = burn rate, in./sec
 a = a constant (peculiar to propellant type)
 P = chamber pressure, psia
 n = burn-rate exponent

The ignition system for this motor is comprised of five solid-propellant igniters installed in an igniter adapter plate in the forward end of the motor.

The nozzle (Fig. 3) is equipped with a hydraulically actuated strut-mounted pintle which moves along the motor longitudinal axis to vary throat area. The pintle hydraulic actuator is located in the strut-mounted centerbody. The change in throat area as a function of pintle position for both the minimum geometric area as determined by ASPC and the effective aerodynamic area determined under cold flow test conditions at AEDC, conducted prior to the test firing of CSRM-4, is shown in Fig. 4. Movement of the pintle 8.35 in. (from the fully extended to the fully retracted position) results in a change in the geometric throat area from 114 to 319 sq in. This area change provides control of chamber pressure, thereby thrust, and propellant extinguishment.

2.2 PINTLE POSITION CONTROL SYSTEM

Position of the nozzle pintle is controlled by means of a closed-loop servocontrol system incorporating an ASPC control console and AEDC command signal generator and hydraulic supply system. The ASPC controller generates the pintle position command voltage as a function of chamber pressure feedback voltage. The AEDC command signal generator provided the time-sequenced reference voltages to the ASPC controller; AEDC interconnects were provided to complete this control loop. The pintle is held in the ignition position by using a potentiometer to supply a reference voltage to the servocontrol loop. After ignition, transfer to chamber pressure feedback voltage control is made, and the potentiometer reference is replaced by a computer reference voltage corresponding to the target chamber pressure feedback voltage. The pintle is retracted to the maximum geometric throat area position for extinguishment (319 sq in.). An ASPC analog computer was utilized to simulate chamber pressure feedback voltage for functional actuation checks of the pintle control system. The hydraulic system was capable of operating at a 4500-psia pressure

level and providing an instantaneous fluid flow rate of 60 gpm with 1000-psi differential across the servo valve.

2.3 TEST CELL AND INSTALLATION

Rocket Development Test Cell (J-5) (Fig. 1 and Ref. 6) is a test complex for testing solid-propellant rocket motors with thrust levels nominally up to 125,000 lbf at simulated altitudes of approximately 100,000 ft. A steam ejector-diffuser system was used in conjunction with rotating exhaust machinery to provide altitude simulation during the firings and coast periods.

2.4 INSTRUMENTATION

Table 1 presents a summary of motor instrumentation. Instrumentation calibration techniques are described in Appendix A. Uncertainties of the J-5 instrument systems are presented in Table 2. The method of calculation of these uncertainties is presented in Ref. 7.

The types of data acquisition and recording systems used during this test were a multiple-input digital data acquisition system scanning each parameter at a basic rate of 200 samples/sec (selected parameters supercommutated to 1000 samples/sec) and recording on magnetic tape; single-input continuous recording analog system recording in pulse form on magnetic tape; frequency modulation (FM) analog systems recording on magnetic tape; and galvanometer-type oscillographs recording at paper speeds of 16 in./sec. Motion-picture cameras provided a permanent visual recording of the firing. All digital data reduction was accomplished with an IBM 370 computer.

3.0 MOTOR CHRONOLOGY AND PROCEDURES

The motor chamber was received at AEDC on May 7, 1973, and was unloaded at the radiographic laboratory. The nozzle assembly was received on June 13, 1973. The conditioning temperature and humidity to which the motor was exposed while at AEDC are summarized in Table 3. An as-received inspection of the motor, nozzle assembly, and other components was performed. No defects or damage during shipment were noted.

Radiographic inspection of the motor was completed on May 18. No propellant voids or separations were noted. A summary of the inspection results was transmitted to ASPC. The original radiographic films are on file at AEDC.

The motor was moved to the Rocket Preparation Area on June 14, and the nozzle assembly was installed on the motor on June 15. Instrumentation (Table 1) was installed in accordance with the ASPC Test Plan (Ref. 8). After installation of the chamber and igniter pressure transducers, the motor was pressure checked in accordance with test procedures supplied by ASPC. The leak rate was within limits specified by ASPC. Test stand adapting equipment was then installed on the motor. Prefire nozzle exit plane measurements were made at 30-deg intervals referenced to 0-deg target down. These measurements are presented in Table 4 along with prefire nozzle throat annular gap measurements taken with the nozzle pintle in the fully extended position. The motor was transported to the test cell, installed, and aligned in the test cell on June 19.

ASPC then electrically balanced, trimmed, and functionally tested the electronic systems for nozzle pintle control. Physical calibration of the nozzle pintle control system in preparation for the test firing was conducted.

Sequence checks for the test were performed on June 22 and June 25. The sequence run checks the operation of the test article and facility systems which support the test. After completion of the sequence checks, the motor igniter squibs were installed, final preparation of facility support systems for the test was performed, and a final test cell inspection was accomplished.

The test cell was evacuated to altitude conditions at 2030 hours on June 25, and instrumentation recorder calibrations were performed. Test cell pressure during calibrations was 0.40 psia. The test firing was accomplished at 2205 hours on June 25. Test results are presented in Section 4.0 of this report. The motor was removed from the test cell on June 26 and transported to the Rocket Preparation Area. Postfire nozzle exit plane measurements were made and recorded in Table 4. The motor was disassembled for inspection on June 27, reassembled, and shipped to ASPC on July 30, 1973.

The methods used to calculate the ballistic parameters presented in this report are presented in Appendix B.

4.0 RESULTS AND DISCUSSION

4.1 GENERAL

The primary test objective of the Aerojet modified, full-scale, heavyweight CSRM-4 test was to demonstrate propellant extinguishment over a range of motor free volumes to provide baseline design data for the Controllable Solid Rocket Motor system.

Five motor firings were programmed, each to consist of a 3-sec burn at 400 psia and a 2-sec burn at 86 psia followed by propellant extinguishment and a 60-sec coast period was scheduled between firings. A summary of motor performance for this test is presented in Table 5.

The ASPC pintle control system experienced "hunting" on the high-pressure step during the first three firings. This resulted in oscillations in pintle position, and thus in chamber pressure and thrust during these firings. These oscillations did not occur on the fourth and fifth firings; however, erosion of the pintle had progressed to the point that the pintle was fully extended against the mechanical stop for the high-pressure step on these two firings.

The ASPC control console has been used throughout the CSRSM program and has been observed to be less than adequate for stable control of motor thrust. Inability to maintain a steady-state thrust level and pintle "hunting" have been characteristic of the control system throughout the program as well as on the firing reported herein.

Since propellant extinguishment was the objective of the CSRSM-4 test and development of a completely adequate and qualified control system is beyond the scope of this test program, the attainment of steady thrust levels was considered to be of secondary importance in the analysis of CSRSM-4 test results.

The higher chamber pressure and thrust levels on the fifth firing as compared with these levels on the fourth firing with the pintle fully extended in both cases is attributed to a greater available propellant burn surface area for the fifth firing.

4.2 FIRST TEST FIRING

The motor was ignited successfully for the first test firing at 88,000-ft (geometric pressure altitude, Z, Ref. 9) simulated pressure altitude. During motor ignition, the nozzle pintle was held in the 88-percent-of-full-extension position which corresponds to a nozzle geometric throat area of 125 sq in. A history of igniter pressure during the ignition transient is presented in Fig. 5. Mode transfer from pintle ignition position control to chamber pressure feedback control of the pintle occurred at $T + 0.160$. Chamber pressure and thrust at the time of mode transfer were 378 psia and 83,800 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 6. Nozzle pintle command voltage and pintle position are presented in Fig. 7. Chamber pressure averaged 335 psia during the high-pressure step and 147 psia during the low-pressure step. The extinguishment command was given at $T + 5.175$ sec

at 183-psia chamber pressure, and extinguishment occurred at $T + 5.78$ sec at 36 psia. Chamber pressure during extinguishment is presented in Fig. 8.

4.3 SECOND TEST FIRING

The motor was successfully ignited for the second test firing at $T + 65.145$ sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held in the fully extended position which corresponds to a nozzle geometric throat area of 113 sq in. A history of igniter pressure during the ignition transient is presented in Fig. 9. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at $T + 65.275$ sec. Chamber pressure and thrust at the time of mode transfer were 430 psia and 81,000 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 10. Nozzle pintle command voltage and pintle position are presented in Fig. 11. Chamber pressure averaged 402 psia during the high-pressure step and 147 psia during the low-pressure step. The extinguishment command was given at $T + 70.285$ sec at 189-psia chamber pressure, and extinguishment occurred at $T + 70.86$ sec at 26 psia. Chamber pressure during extinguishment is presented in Fig. 12.

4.4 THIRD TEST FIRING

The motor was successfully ignited for the third test firing at $T + 130.245$ sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held in the fully extended position. A history of igniter pressure during the ignition transient is presented in Fig. 13. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at $T + 130.385$ sec. Chamber pressure and thrust at the time of mode transfer were 316 psia and 62,400 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 14. Nozzle pintle command voltage and pintle position are presented in Fig. 15. Chamber pressure averaged 274 psia during the high-pressure step and 136 psia during the low-pressure step. The extinguishment command was given at $T + 135.425$ sec at 135-psia chamber pressure, and extinguishment occurred at $T + 135.85$ sec at 32 psia. Chamber pressure during extinguishment is presented in Fig. 16.

4.5 FOURTH TEST FIRING

The motor was successfully ignited for the fourth test firing at $T + 195.360$ sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held

in the fully extended position. A history of igniter pressure during the ignition transient is presented in Fig. 17. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at $T + 195.505$ sec. Chamber pressure and thrust at the time of mode transfer were 238 psia and 44,900 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 18. Nozzle pintle command voltage and pintle position are presented in Fig. 19. Chamber pressure averaged 224 psia during the high-pressure step and 127 psia during the low-pressure step. The extinguishment command was given at $T + 200.520$ sec at 151-psia chamber pressure, and extinguishment occurred at $T + 201.05$ sec at 30 psia. Chamber pressure during extinguishment is presented in Fig. 20.

4.6 FIFTH TEST FIRING

The motor was successfully ignited for the fifth test firing at $T + 260.480$ sec at 89,000-ft simulated pressure altitude. During motor ignition, the nozzle pintle was held in the fully extended position. A history of igniter pressure during the ignition transient is presented in Fig. 21. Mode transfer from pintle position control to chamber pressure feedback control of the pintle occurred at $T + 260.625$ sec. Chamber pressure and thrust at the time of mode transfer were 216 psia and 40,000 lbf, respectively.

Vacuum axial thrust, chamber pressure, and test cell pressure during the firing are presented in Fig. 22. Nozzle pintle command voltage and pintle position are presented in Fig. 23. Chamber pressure averaged 277 psia during the high-pressure step and 127 psia during the low-pressure step. The extinguishment command was given at 265.645 sec at 120-psia chamber pressure, and extinguishment occurred at 266.12 sec at 26 psia. Chamber pressure during extinguishment is presented in Fig. 24.

4.7 STRUCTURAL INTEGRITY

Postfire condition of the motor (Fig. 25) was visually determined to be satisfactory. There were no structural anomalies noted during postfire disassembly and inspection (Fig. 26) of the motor at AEDC.

5.0 SUMMARY OF RESULTS

ASPC modified, full-scale, heavyweight CSRM-4 was tested at simulated pressure altitude in Rocket Development Test Cell J-5 at AEDC on June 25, 1973. The primary objective of the test was to demonstrate propellant extinguishment at the conclusion of each of five identical programmed firings. The results of the test are summarized as follows:

1. Motor propellant extinguishment was demonstrated when commanded from chamber pressure levels of 183, 189, 135, 151, and 120 psia on the first through the fifth firings, respectively. The chamber pressure levels at propellant extinguishment on the five firings were 36, 26, 32, 30, and 26 psia, respectively.
2. Motor postfire condition was satisfactory.

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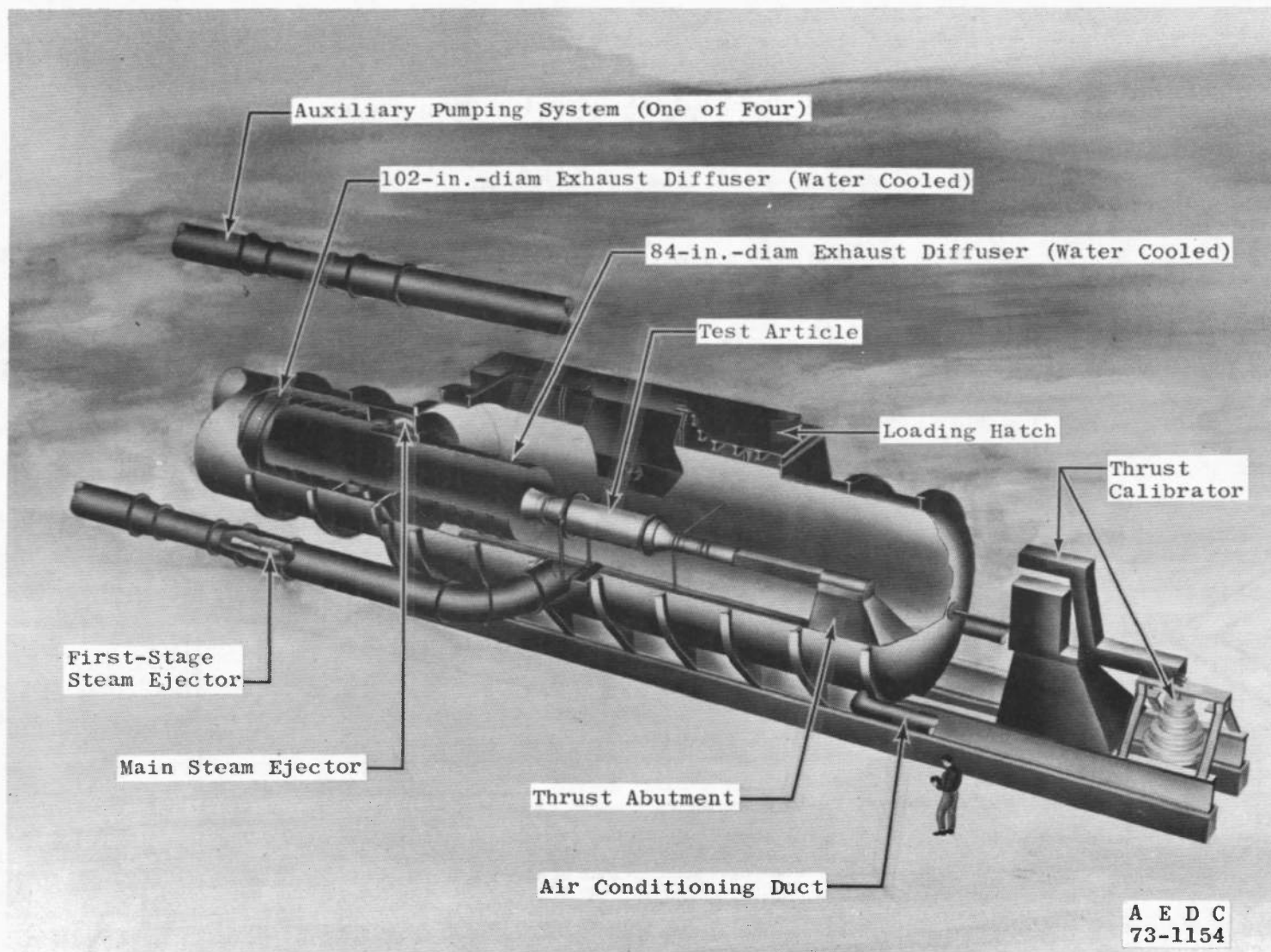
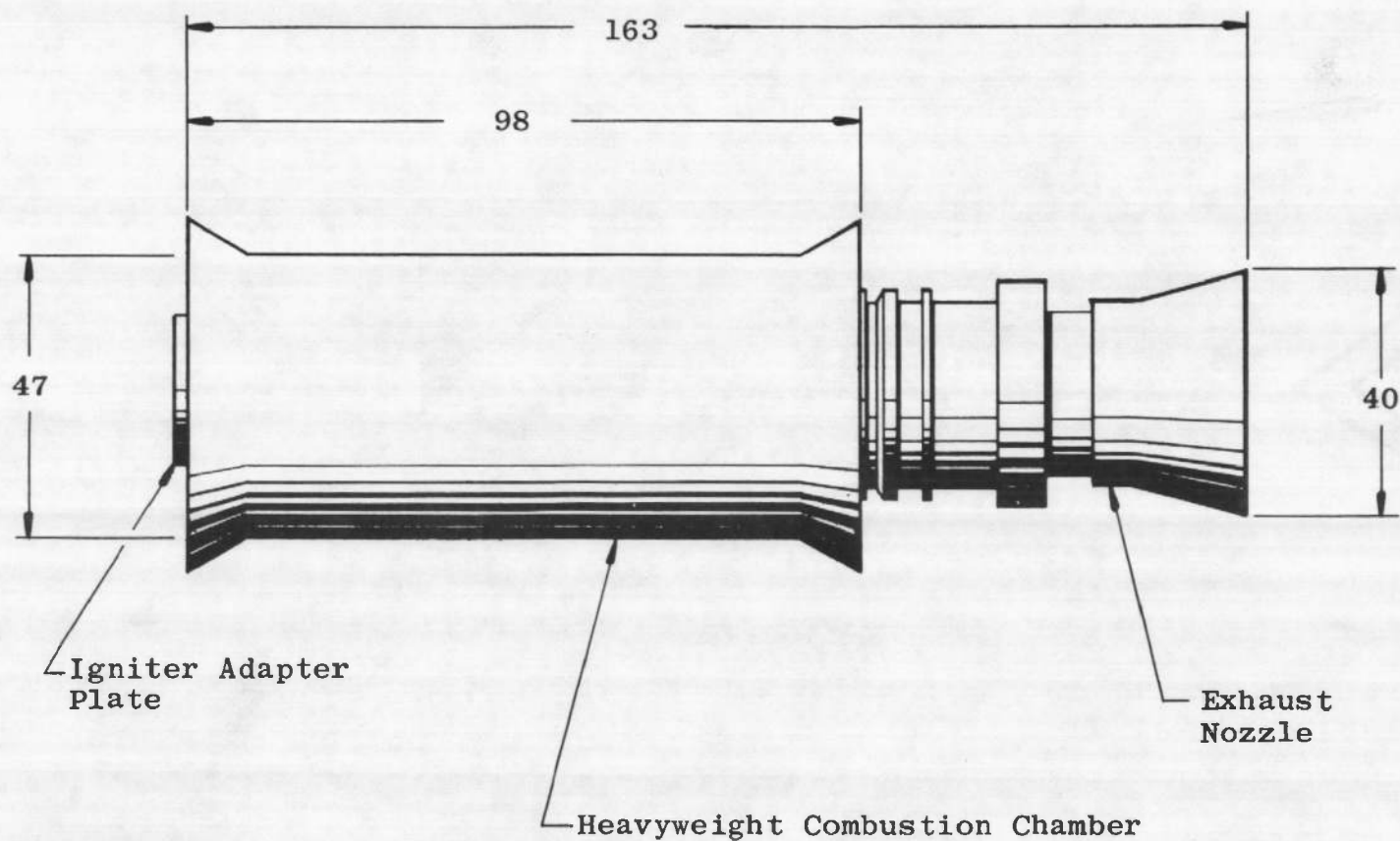


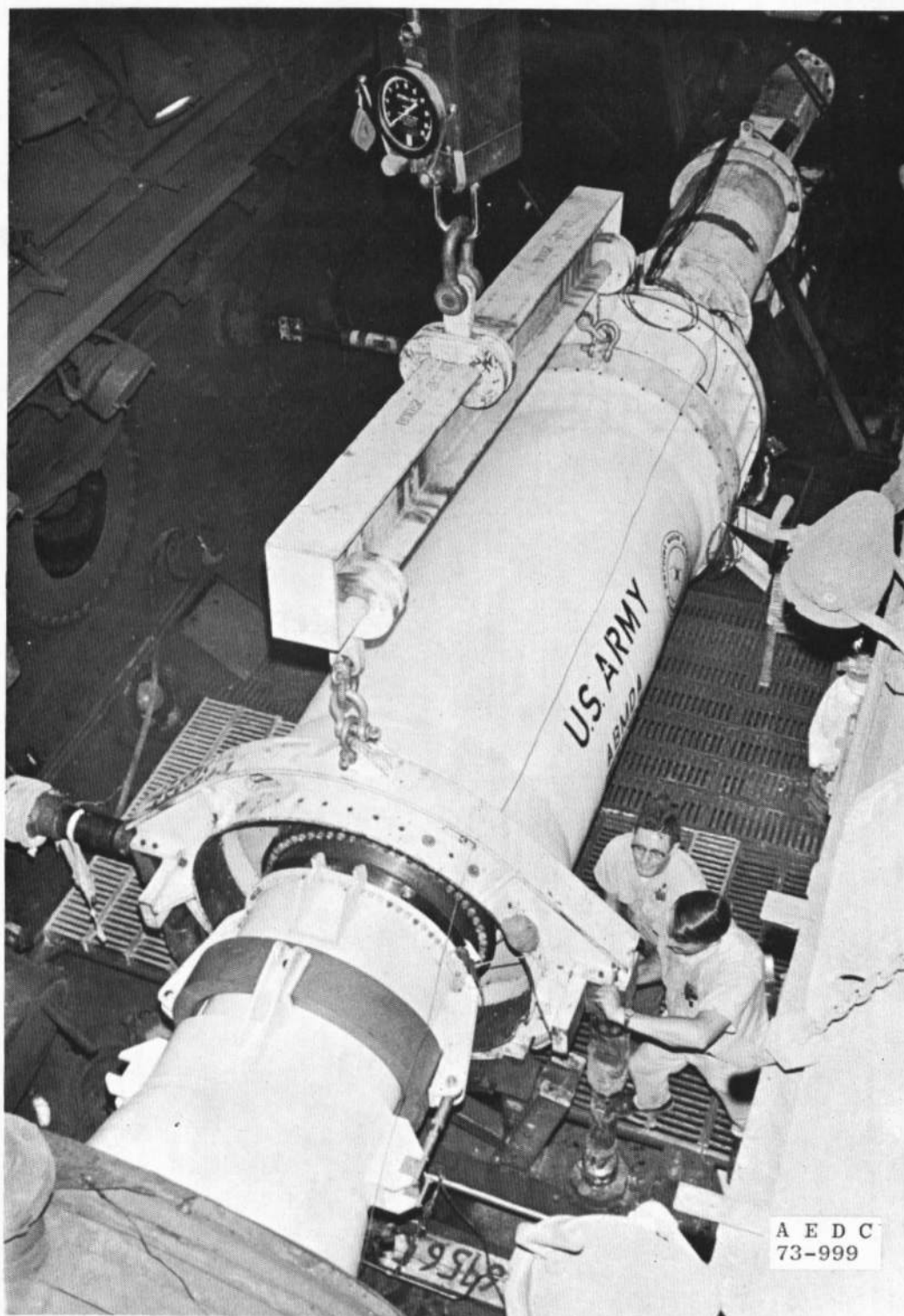
Figure 1. Rocket development test cell J-5.



All Dimensions in Inches

a. Schematic

Figure 2. ASPC modified, full-scale, heavyweight, controllable solid rocket motor.



b. Motor installation in J-5 test cell.
Figure 2. Concluded.

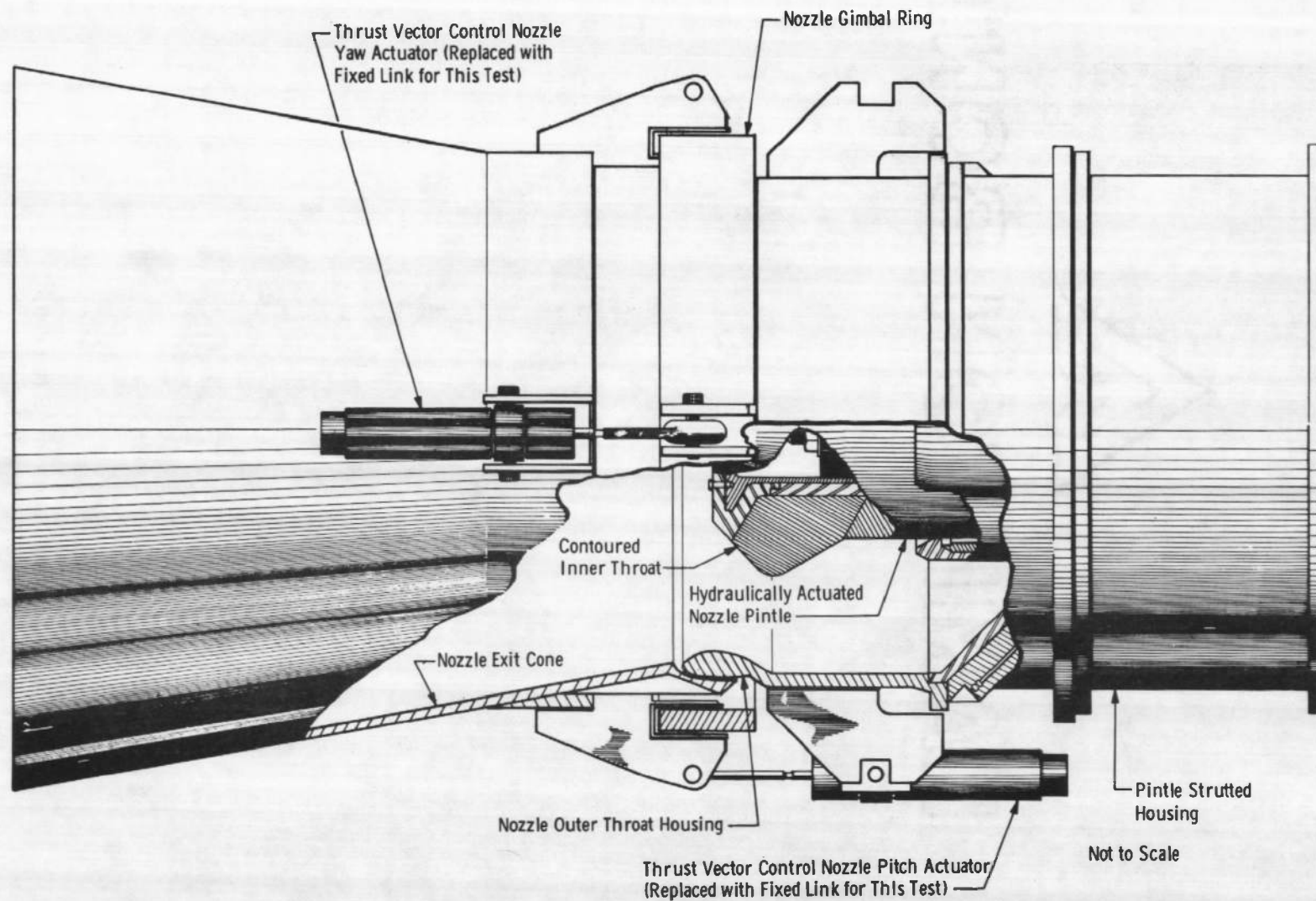


Figure 3. Nozzle assembly.

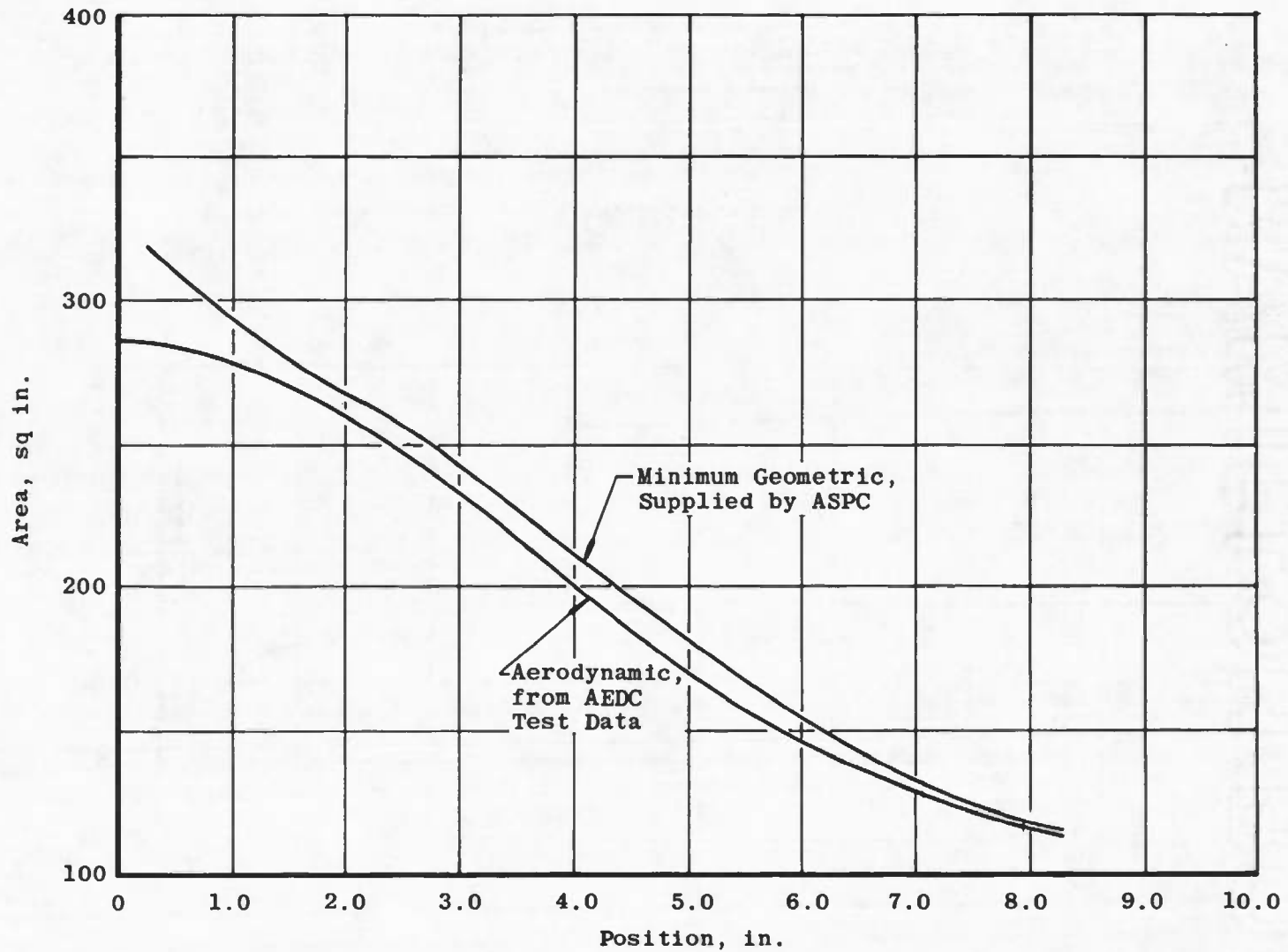


Figure 4. Nozzle throat area versus pintle position.

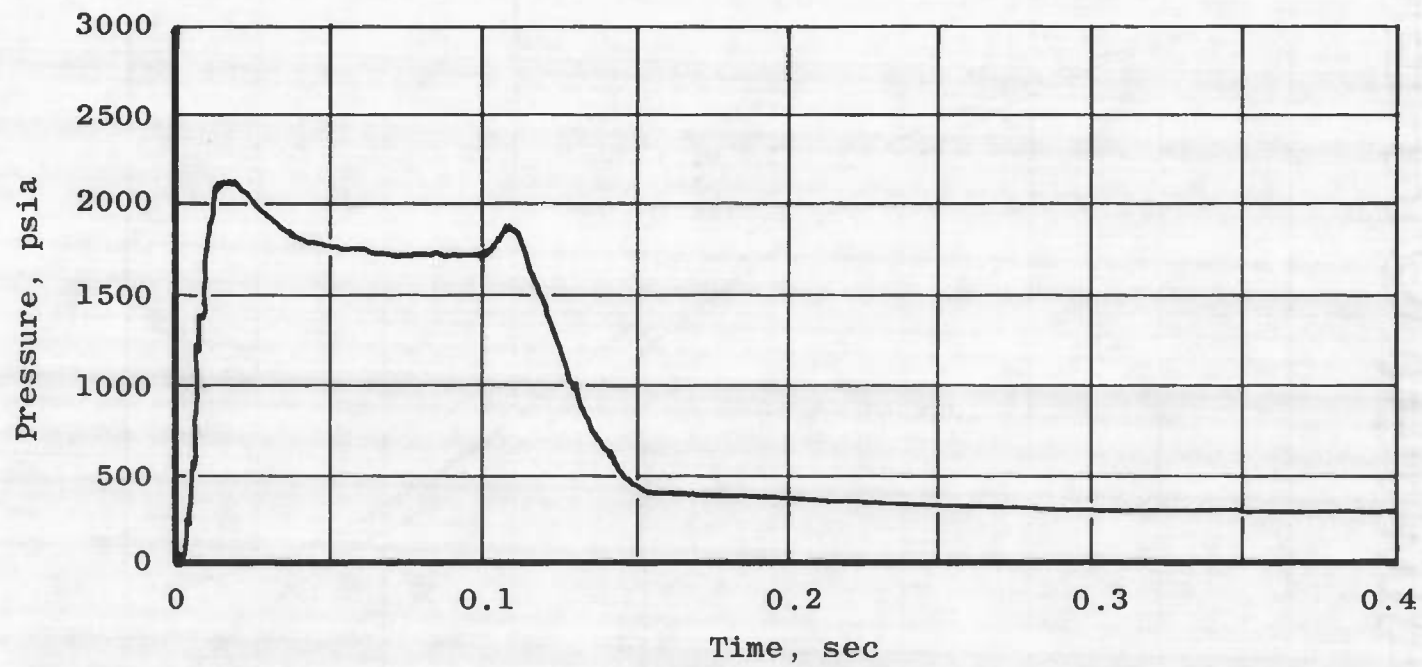


Figure 5. Igniter pressure during ignition transient, first firing.

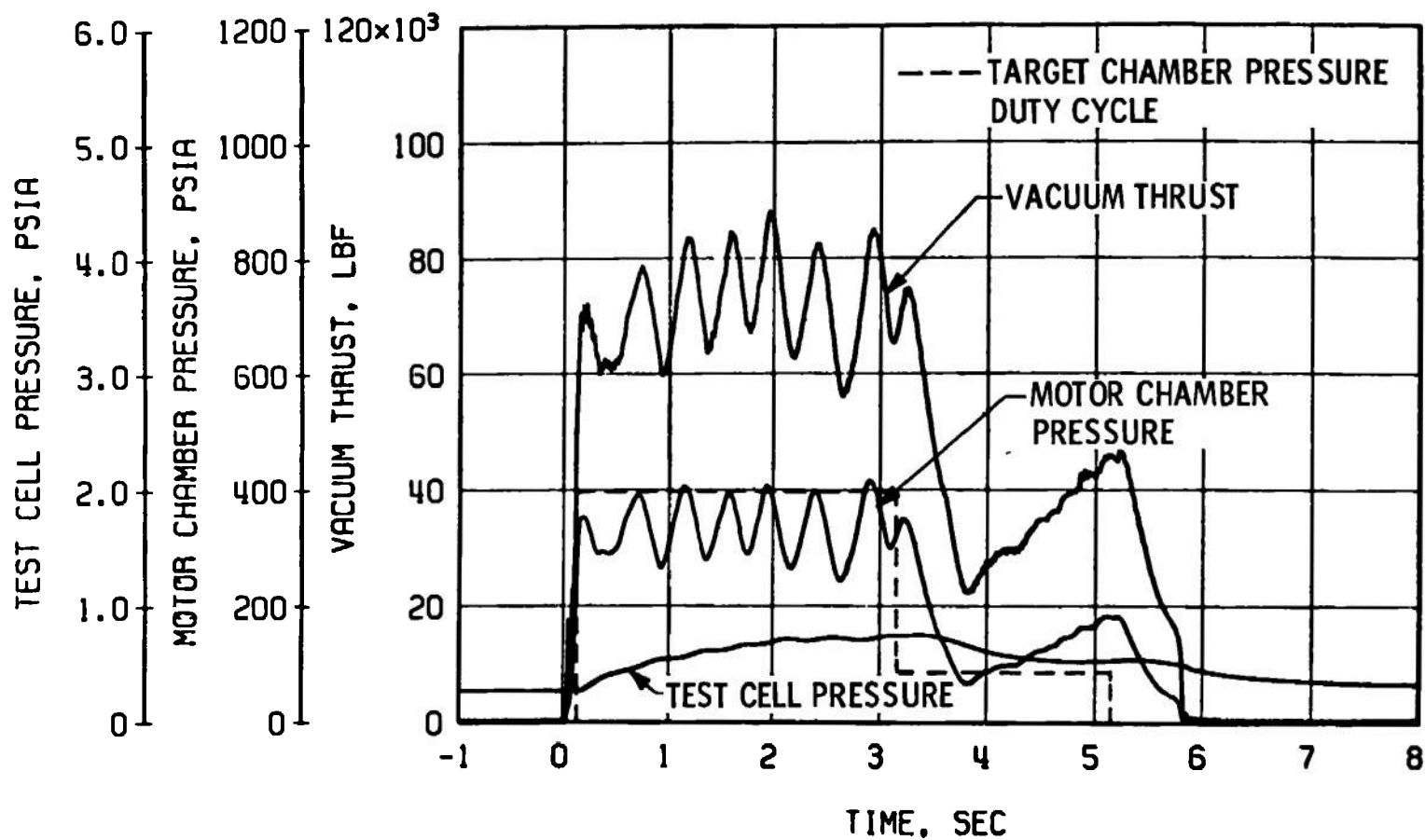
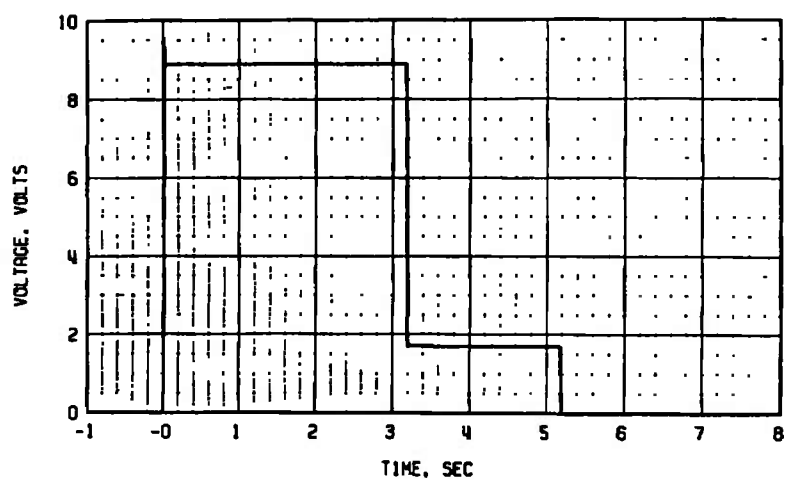
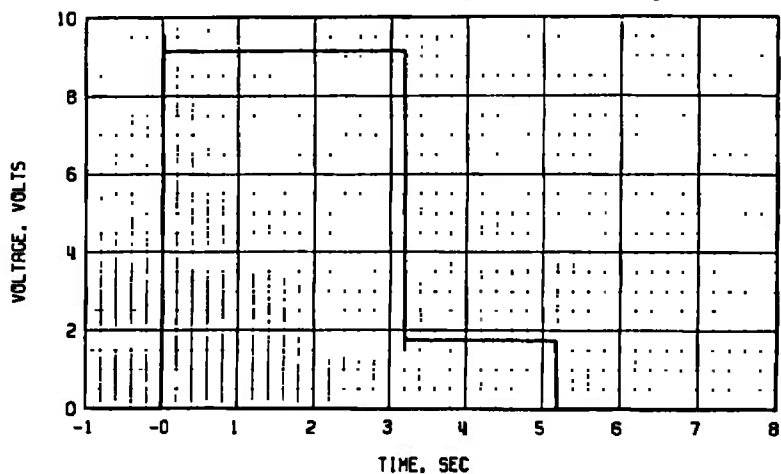


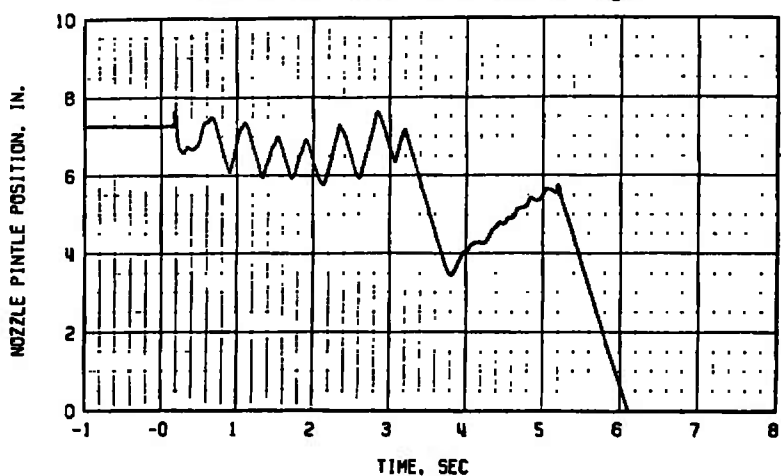
Figure 6. Vacuum axial thrust, chamber pressure, and test cell pressure, first firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 7. Nozzle pintle command voltage and position, first firing.

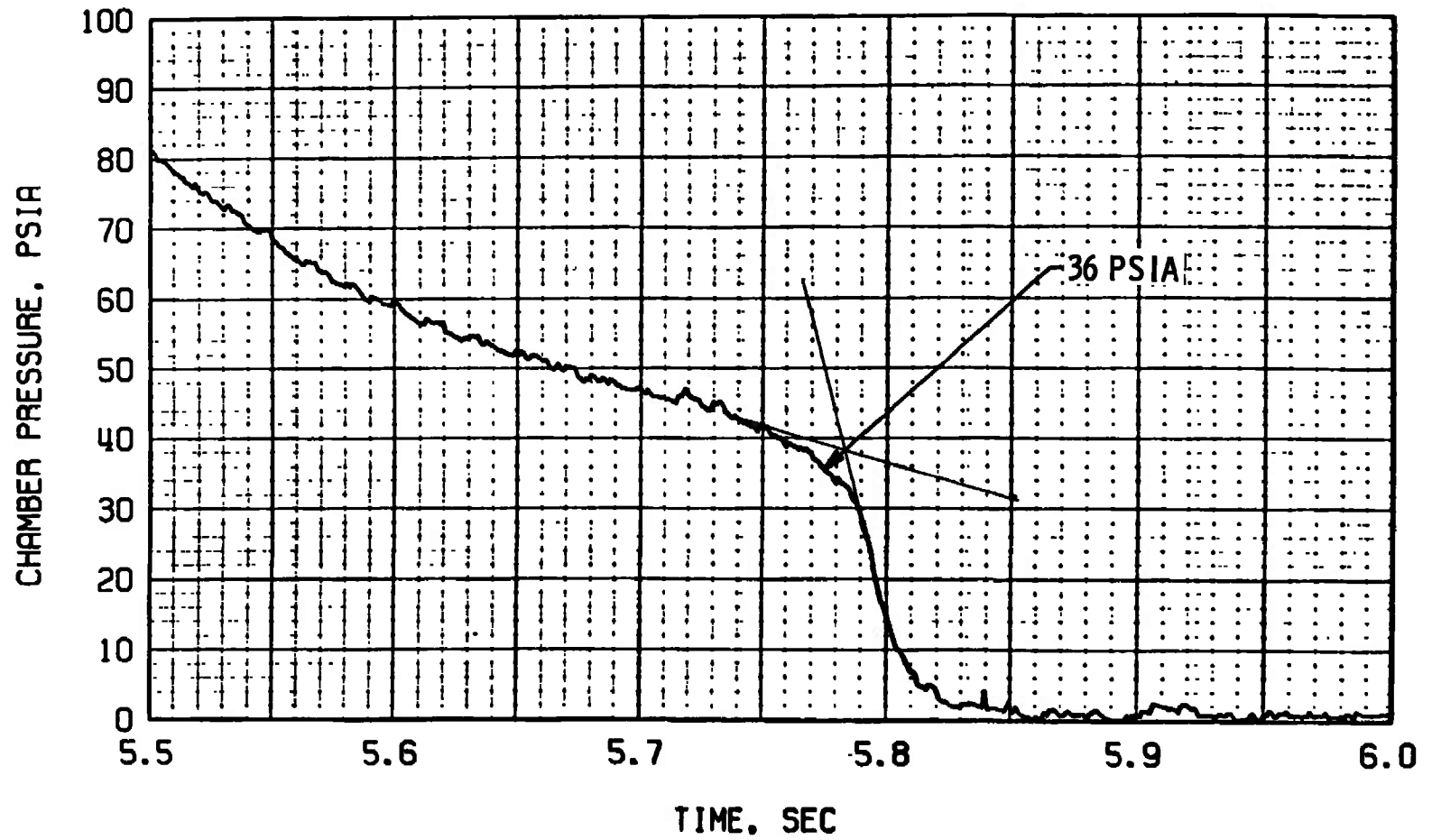


Figure 8. Chamber pressure during extinguishment, first firing.

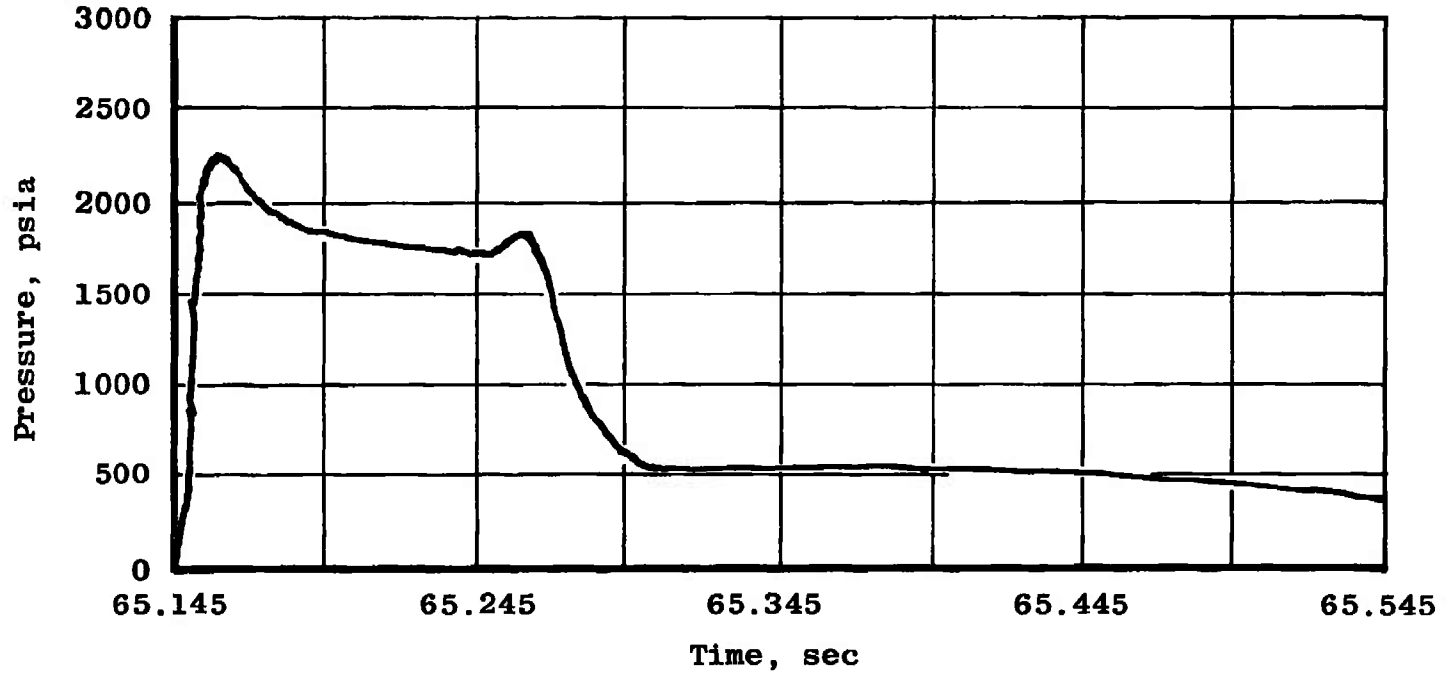


Figure 9. Igniter pressure during ignition transient, second firing.

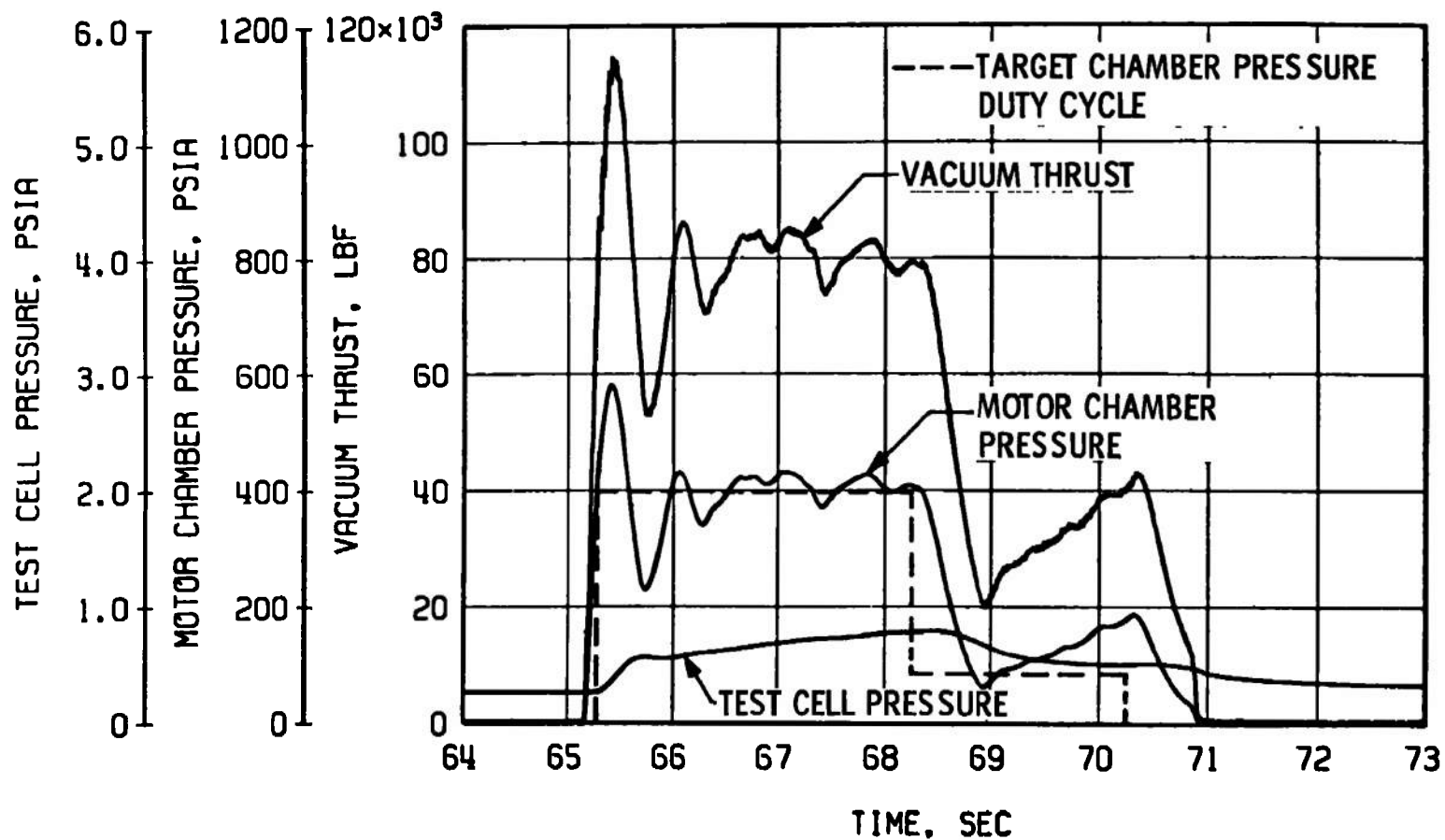


Figure 10. Vacuum axial thrust, chamber pressure, and test cell pressure, second firing.

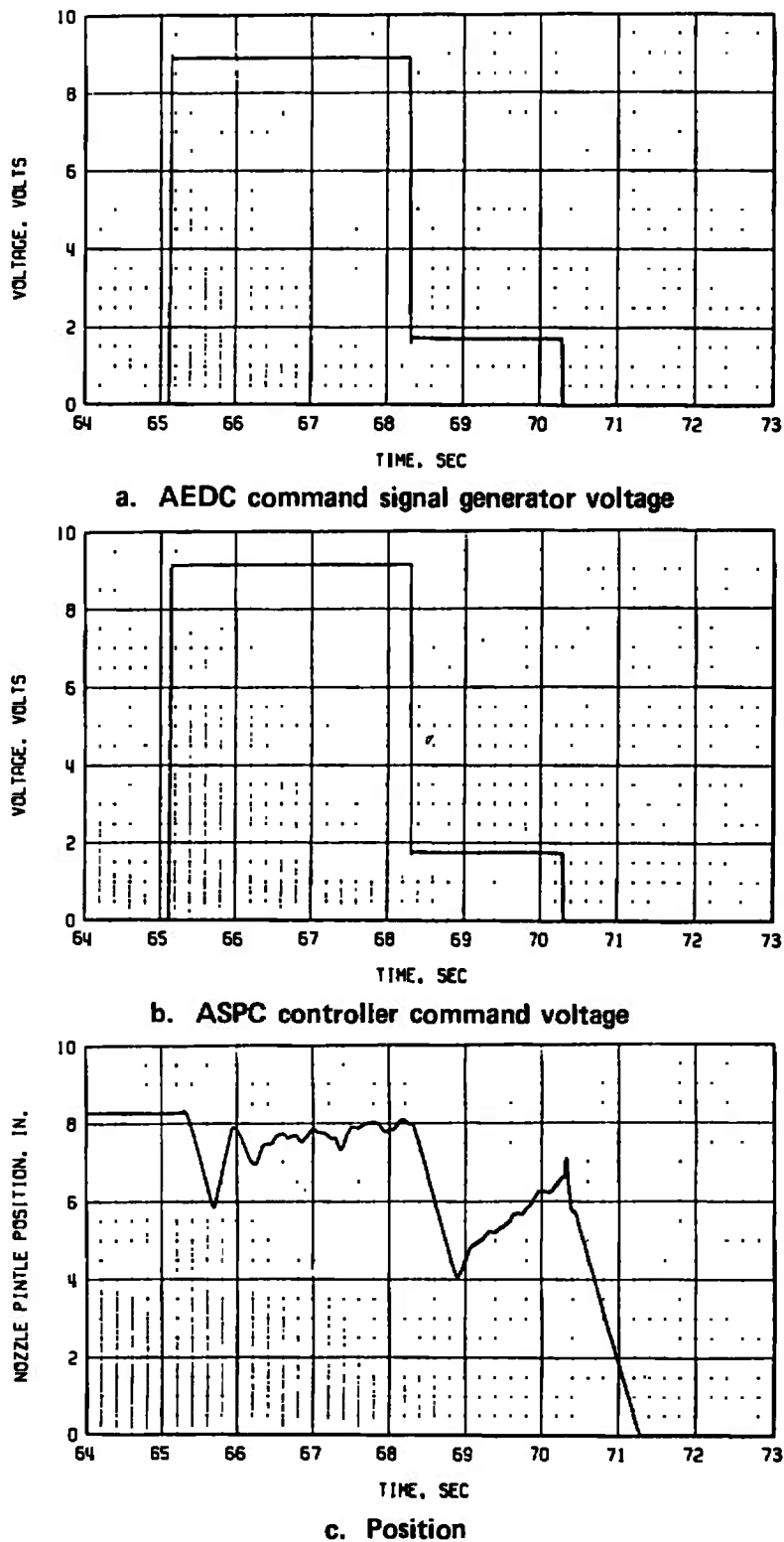


Figure 11. Nozzle pintle command voltage and position, second firing.

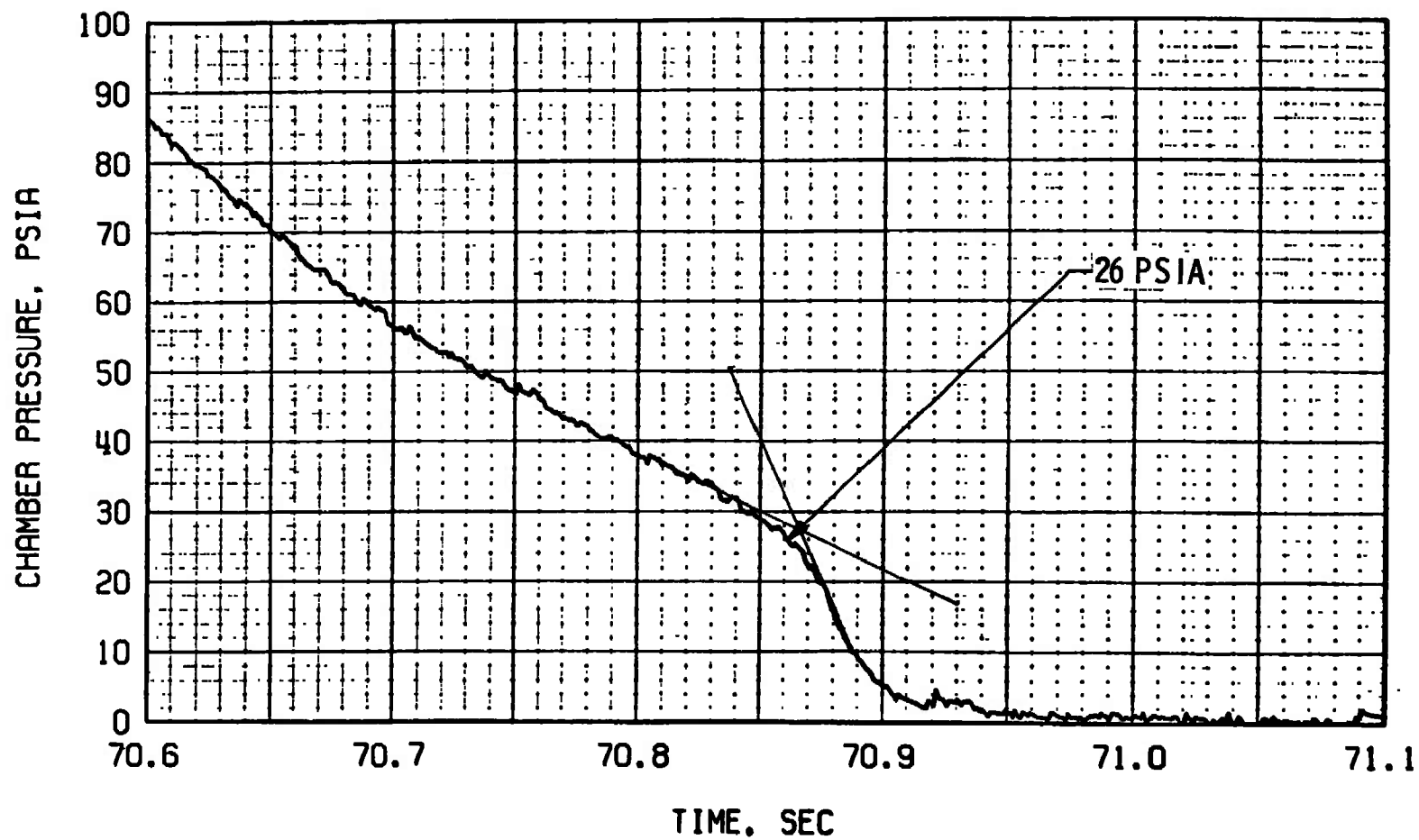


Figure 12. Chamber pressure during extinguishment, second firing.

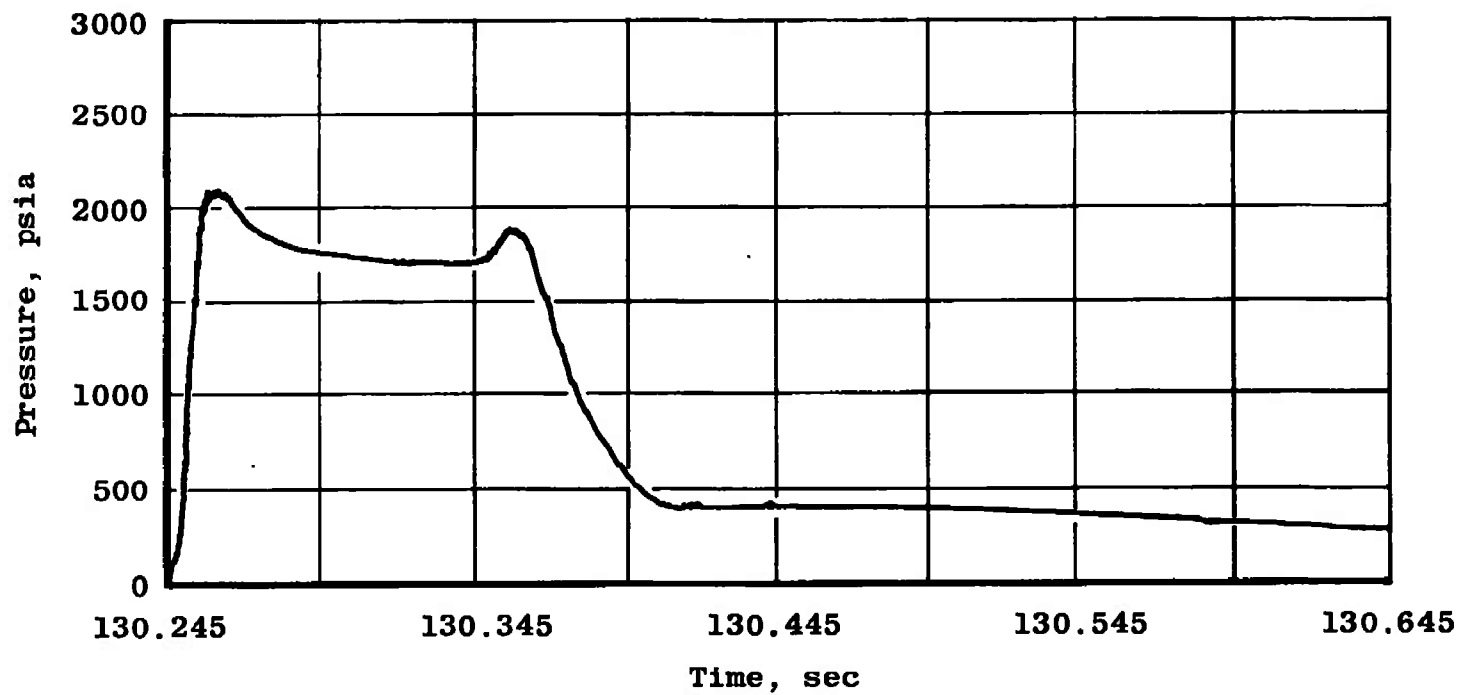


Figure 13. Igniter pressure during ignition transient, third firing.

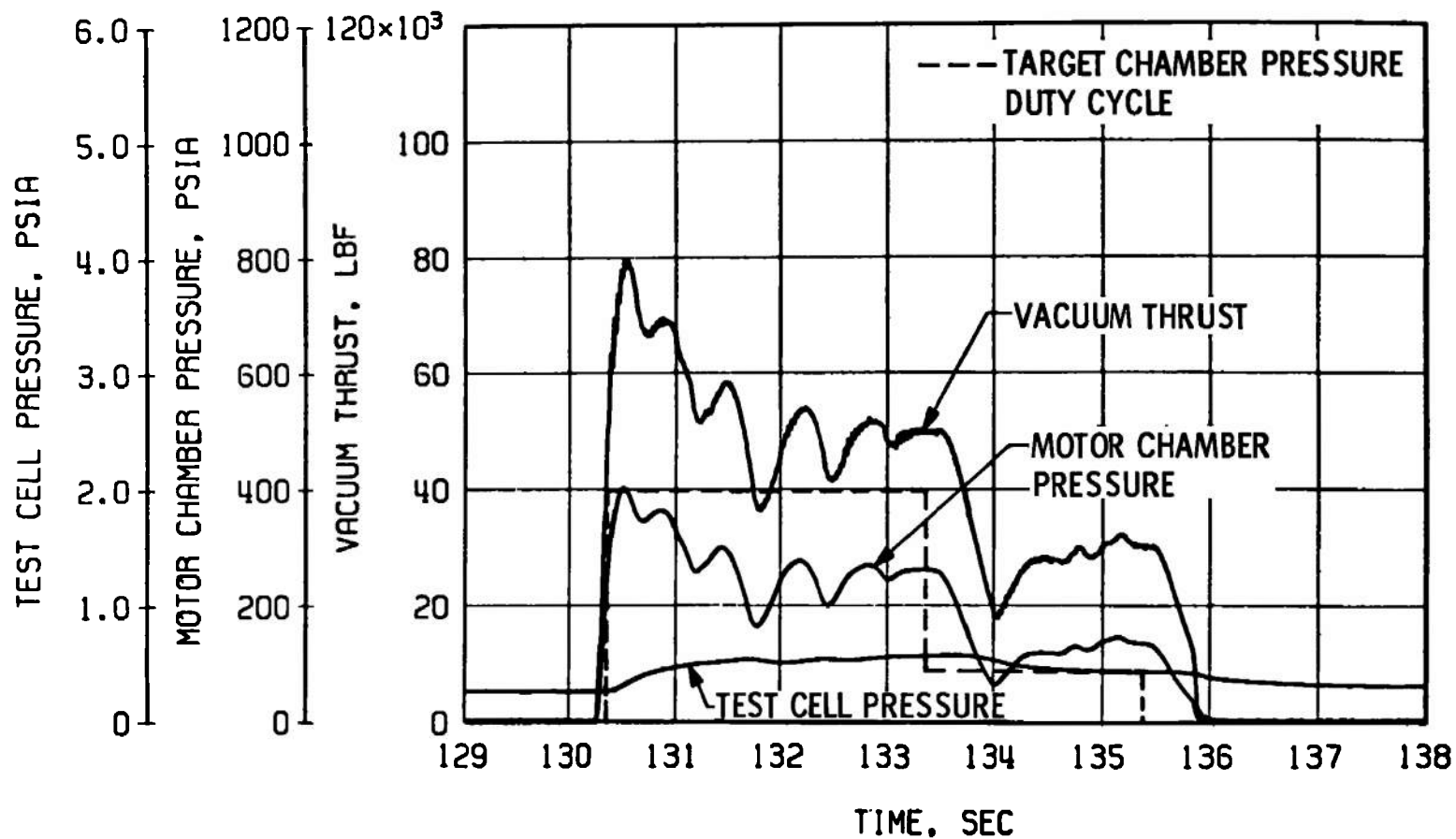
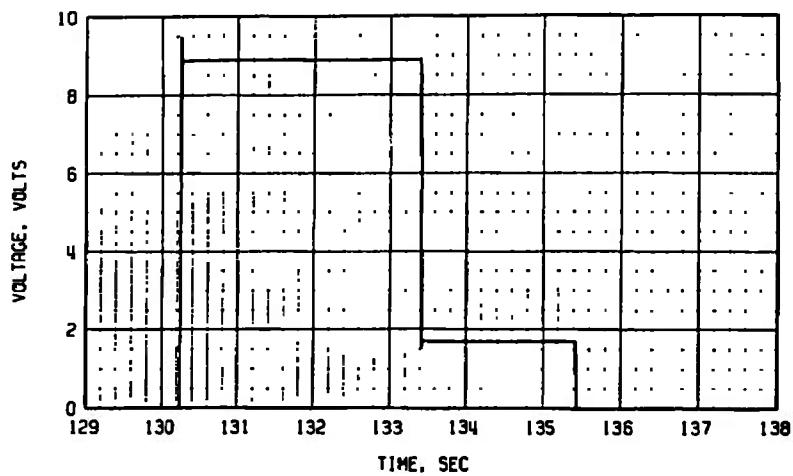
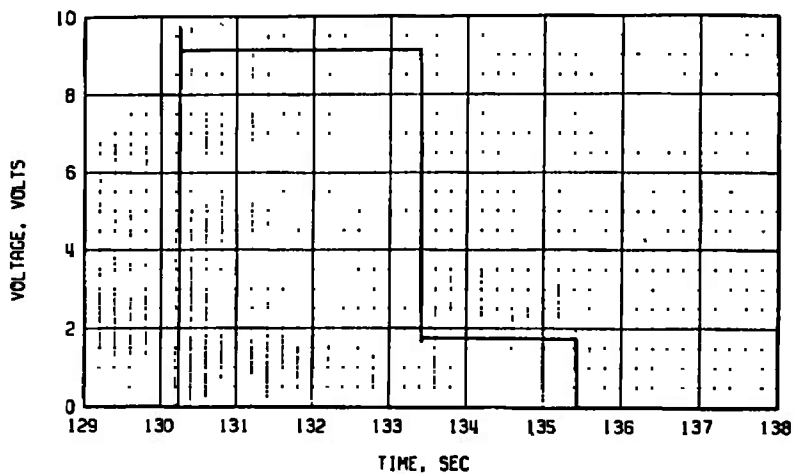


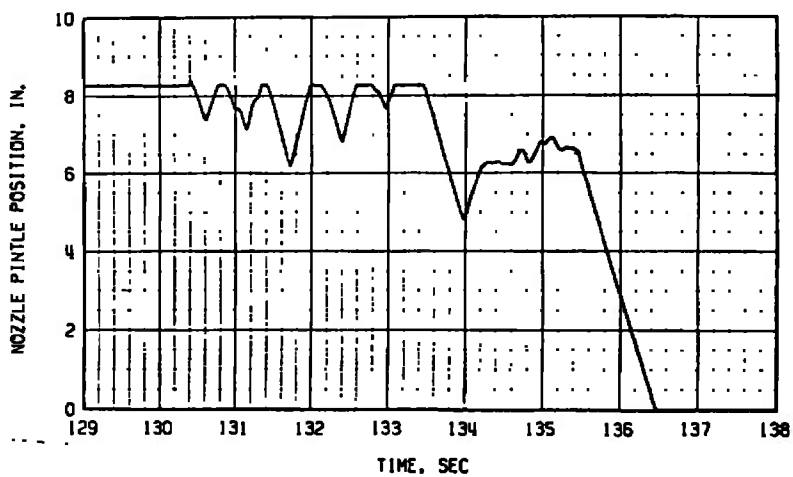
Figure 14. Vacuum axial thrust, chamber pressure, and test cell pressure, third firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 15. Nozzle pintle command voltage and position, third firing.

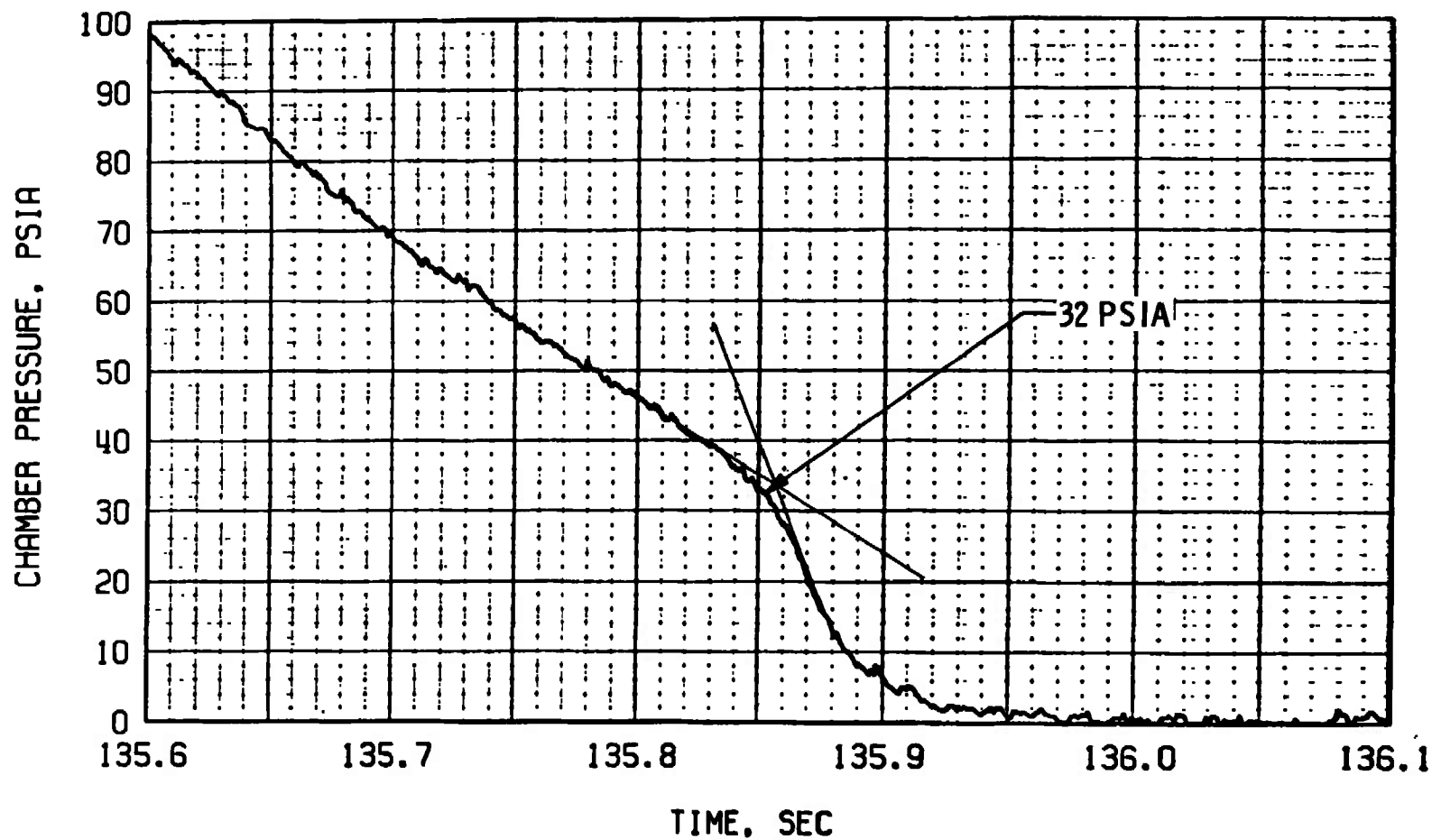


Figure 16. Chamber pressure during extinguishment, third firing.

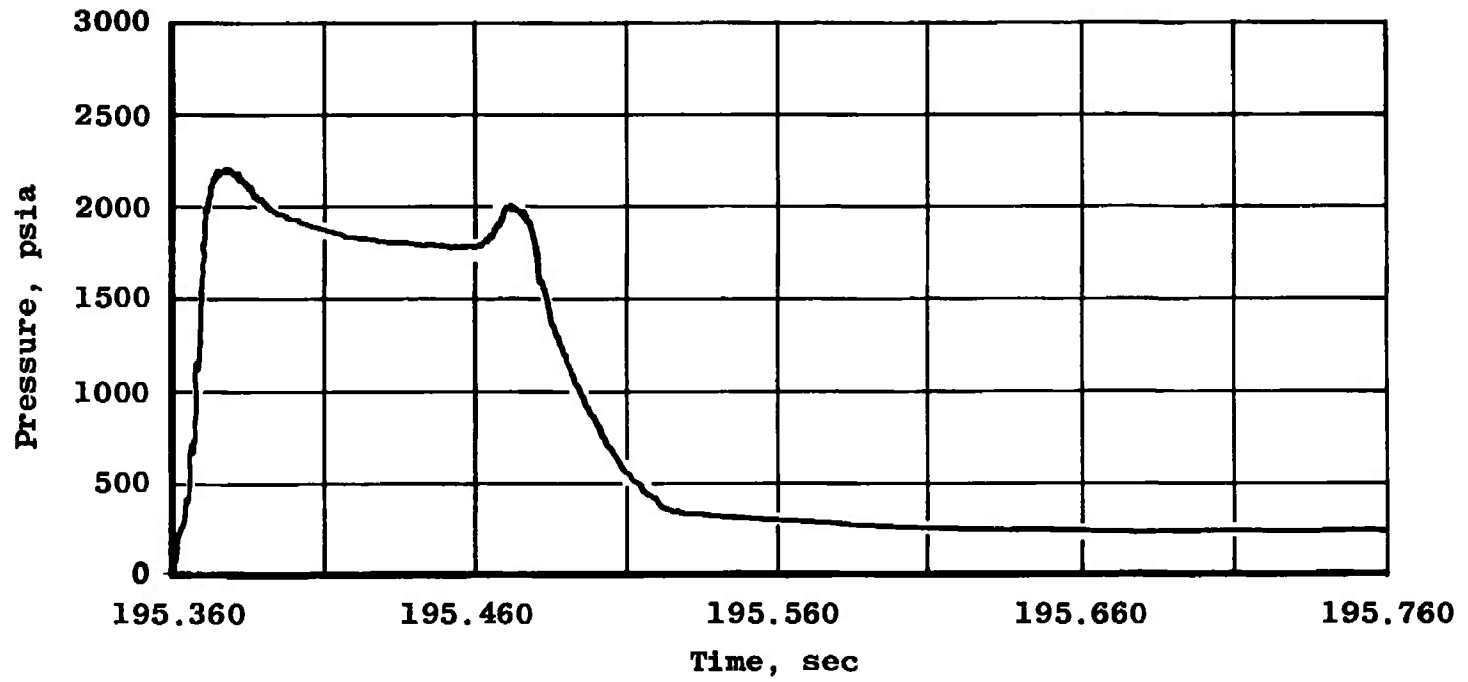


Figure 17. Igniter pressure during ignition transient, fourth firing.

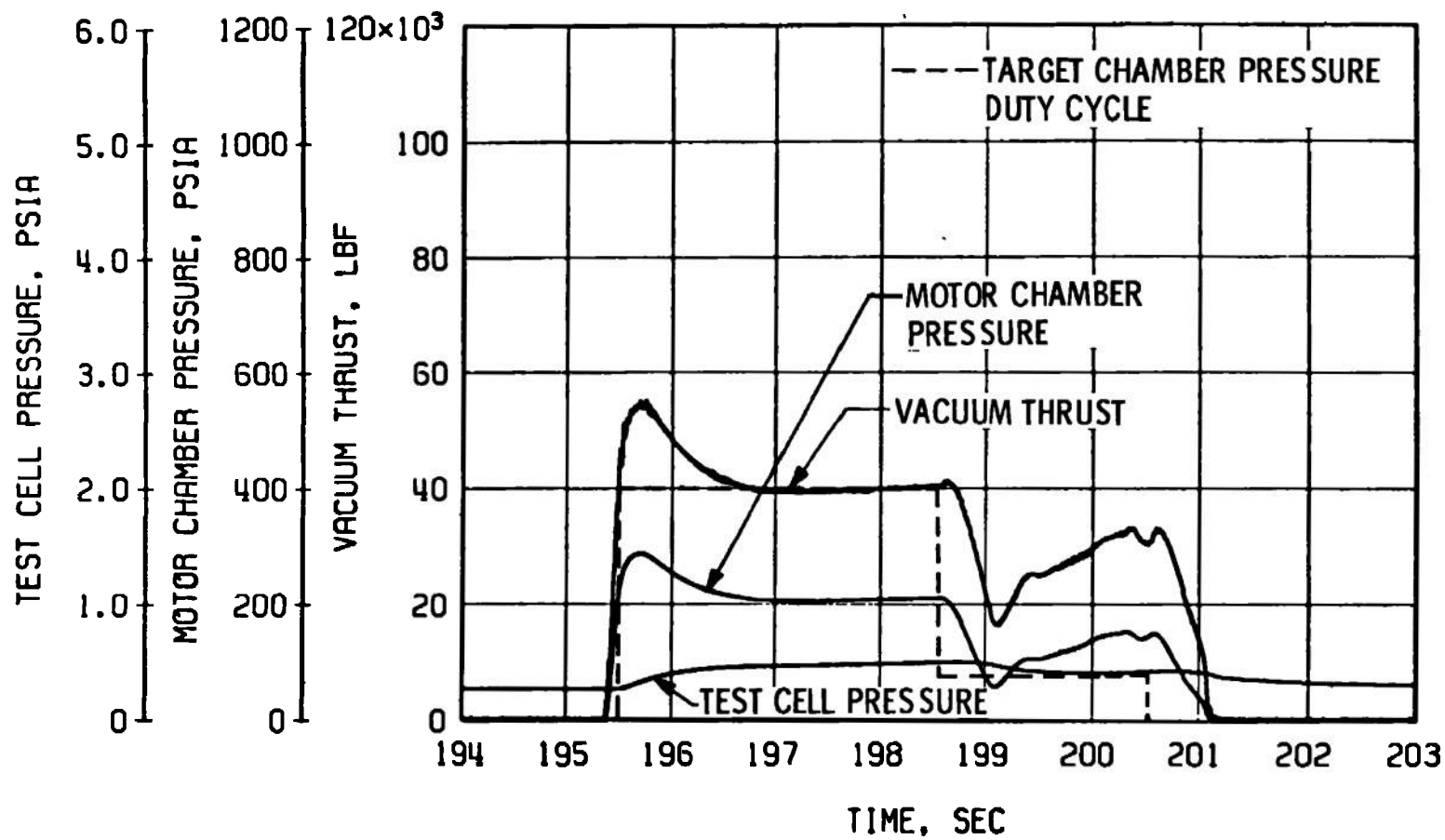
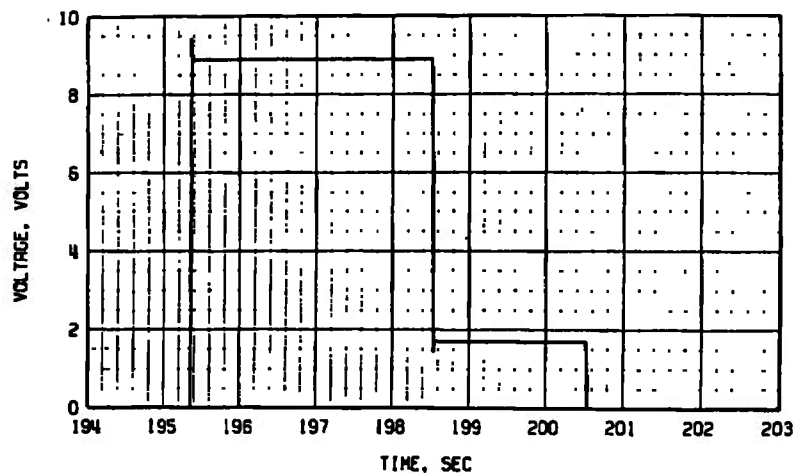
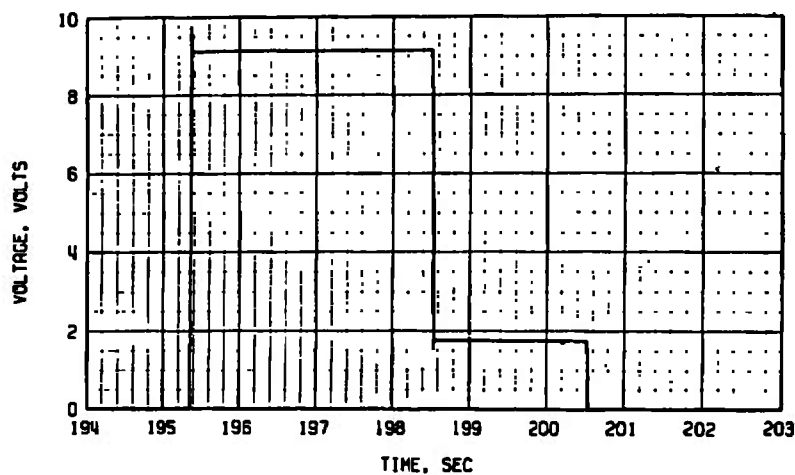


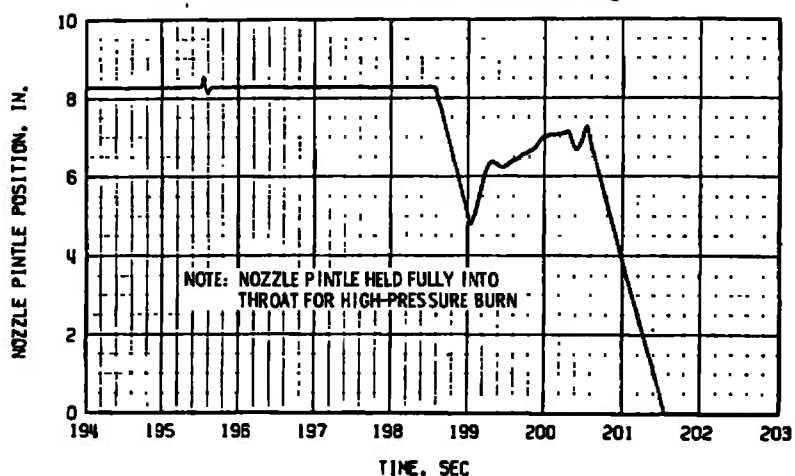
Figure 18. Vacuum axial thrust, chamber pressure, and test cell pressure, fourth firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 19. Nozzle pintle command voltage and position, fourth firing.

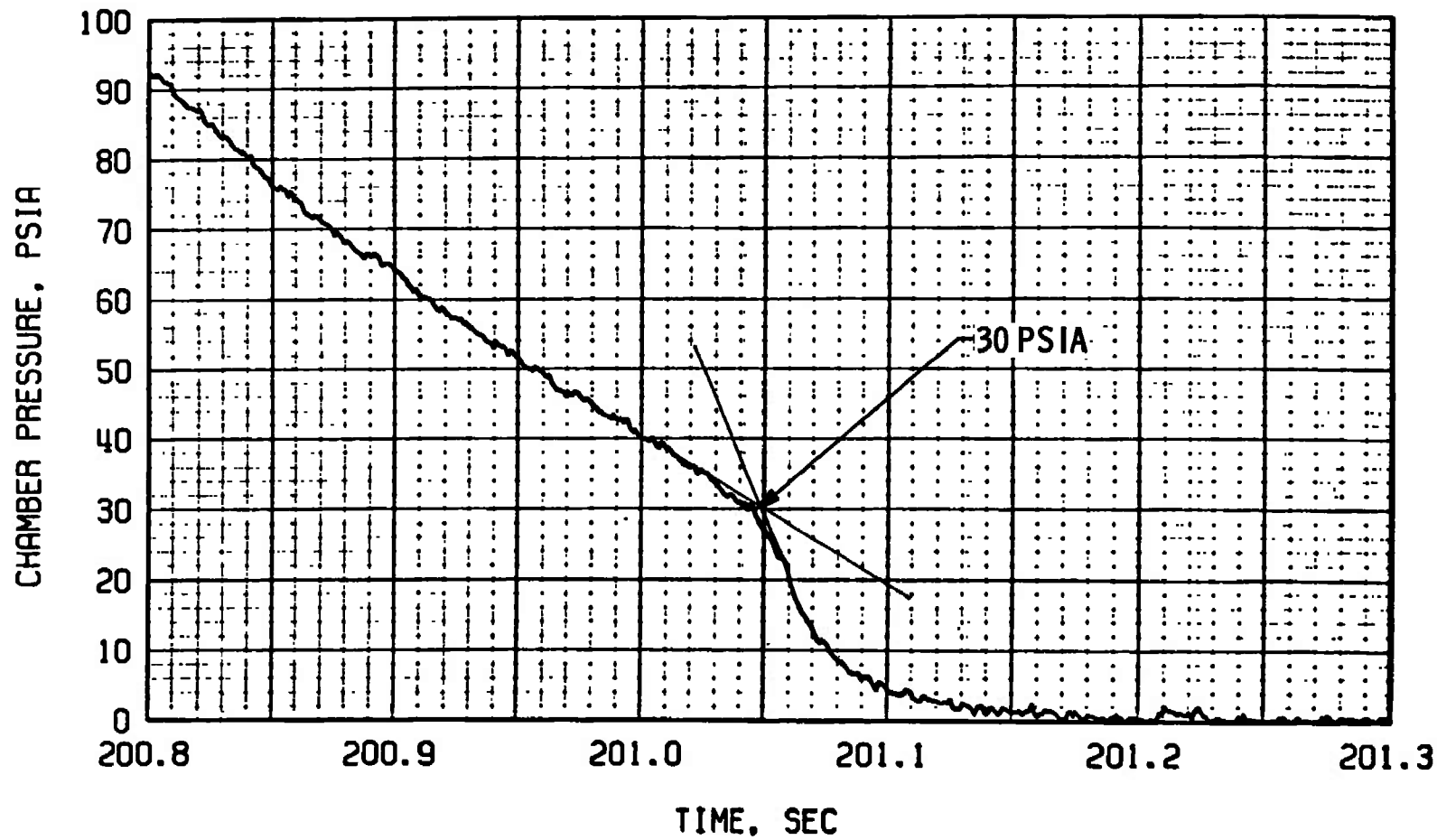


Figure 20. Chamber pressure during extinguishment, fourth firing.

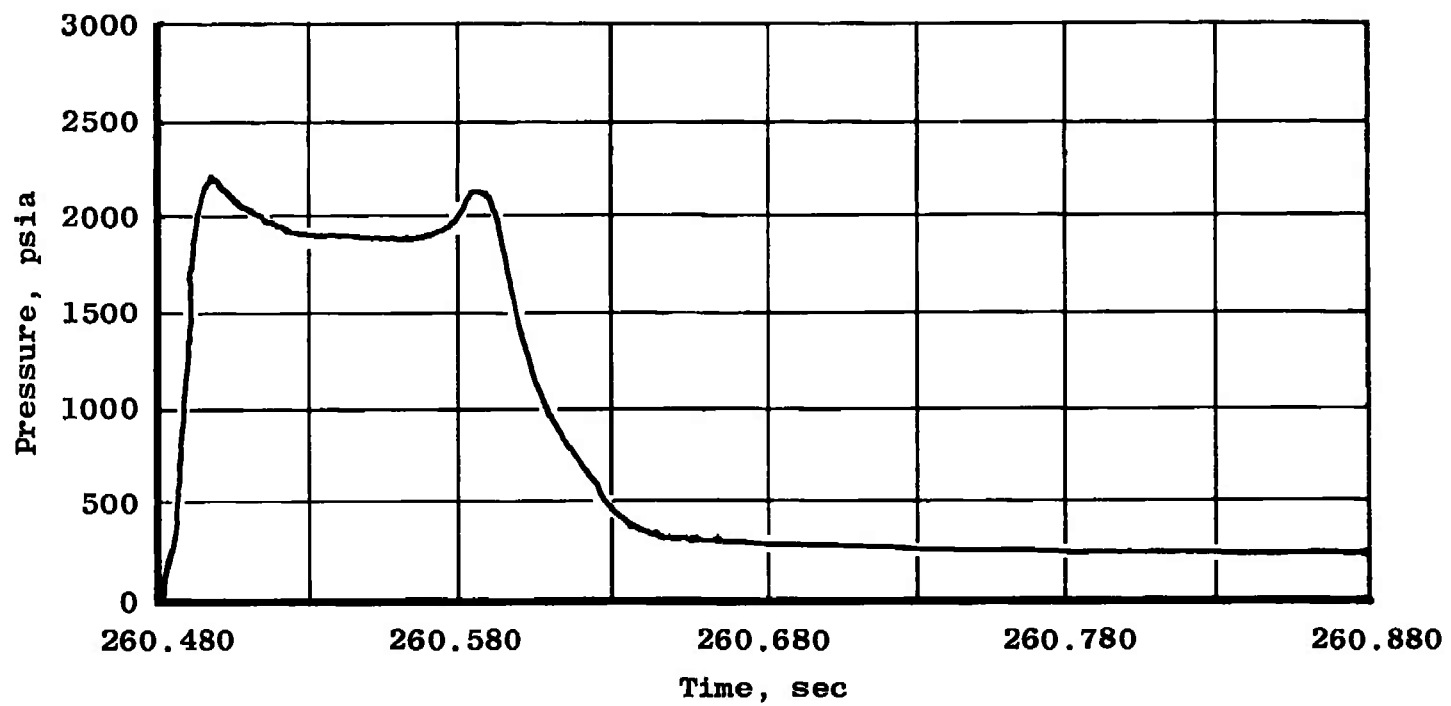


Figure 21. Igniter pressure during ignition transient, fifth firing.

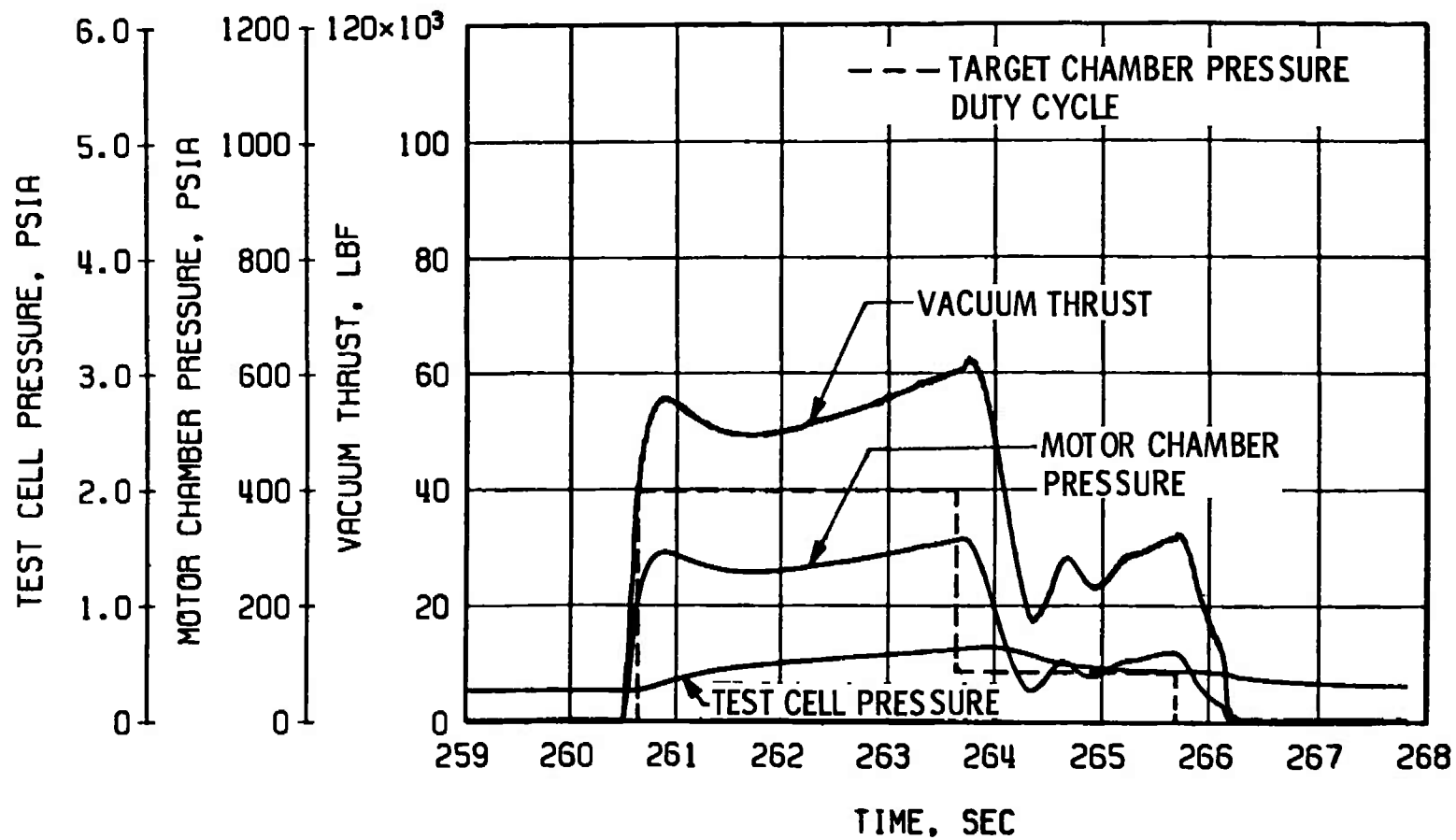
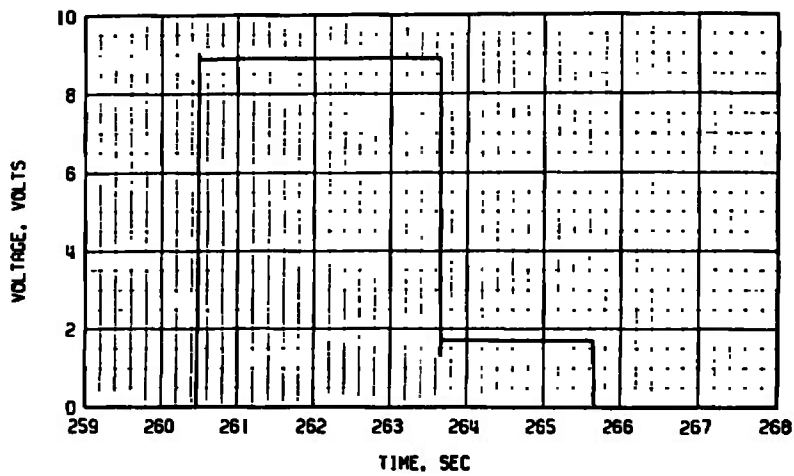
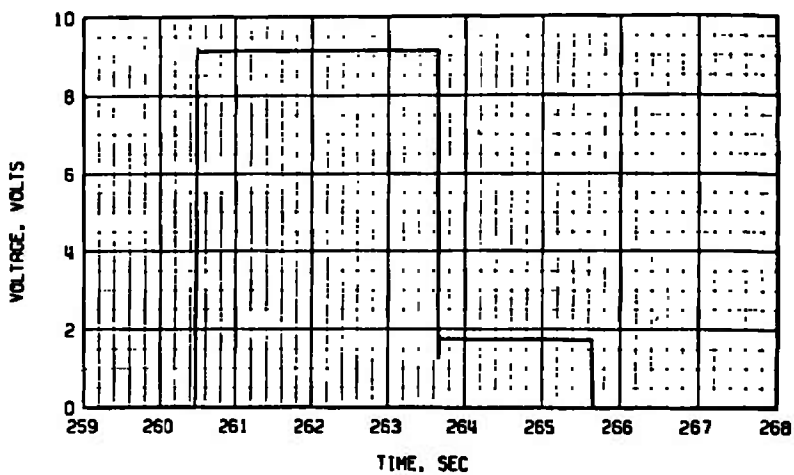


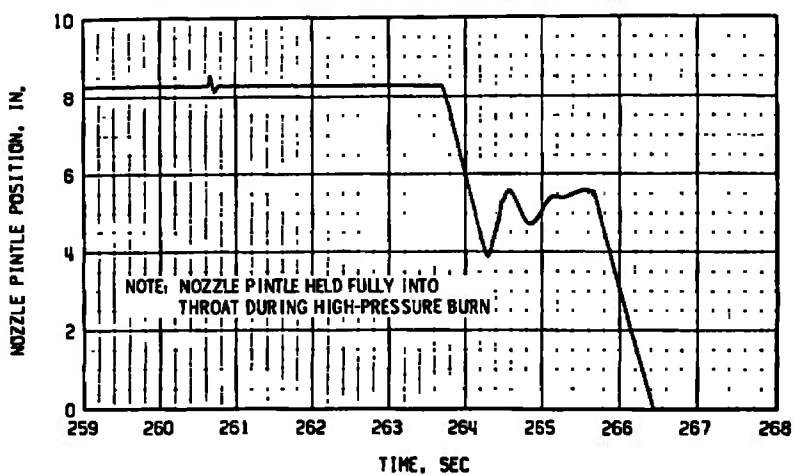
Figure 22. Vacuum axial thrust, chamber pressure, and test cell pressure, fifth firing.



a. AEDC command signal generator voltage



b. ASPC controller command voltage



c. Position

Figure 23. Nozzle pintle command voltage and position, fifth firing.

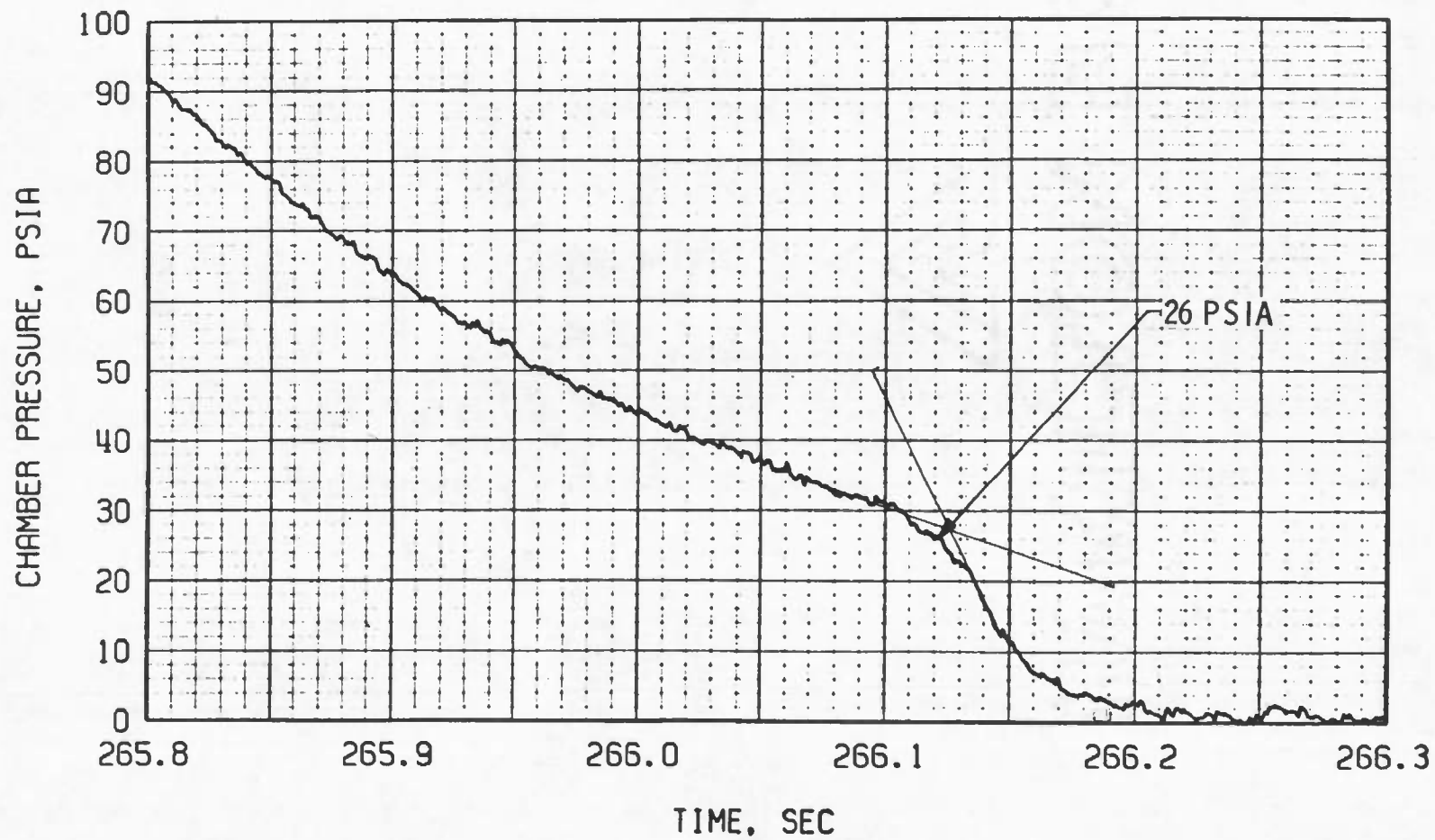
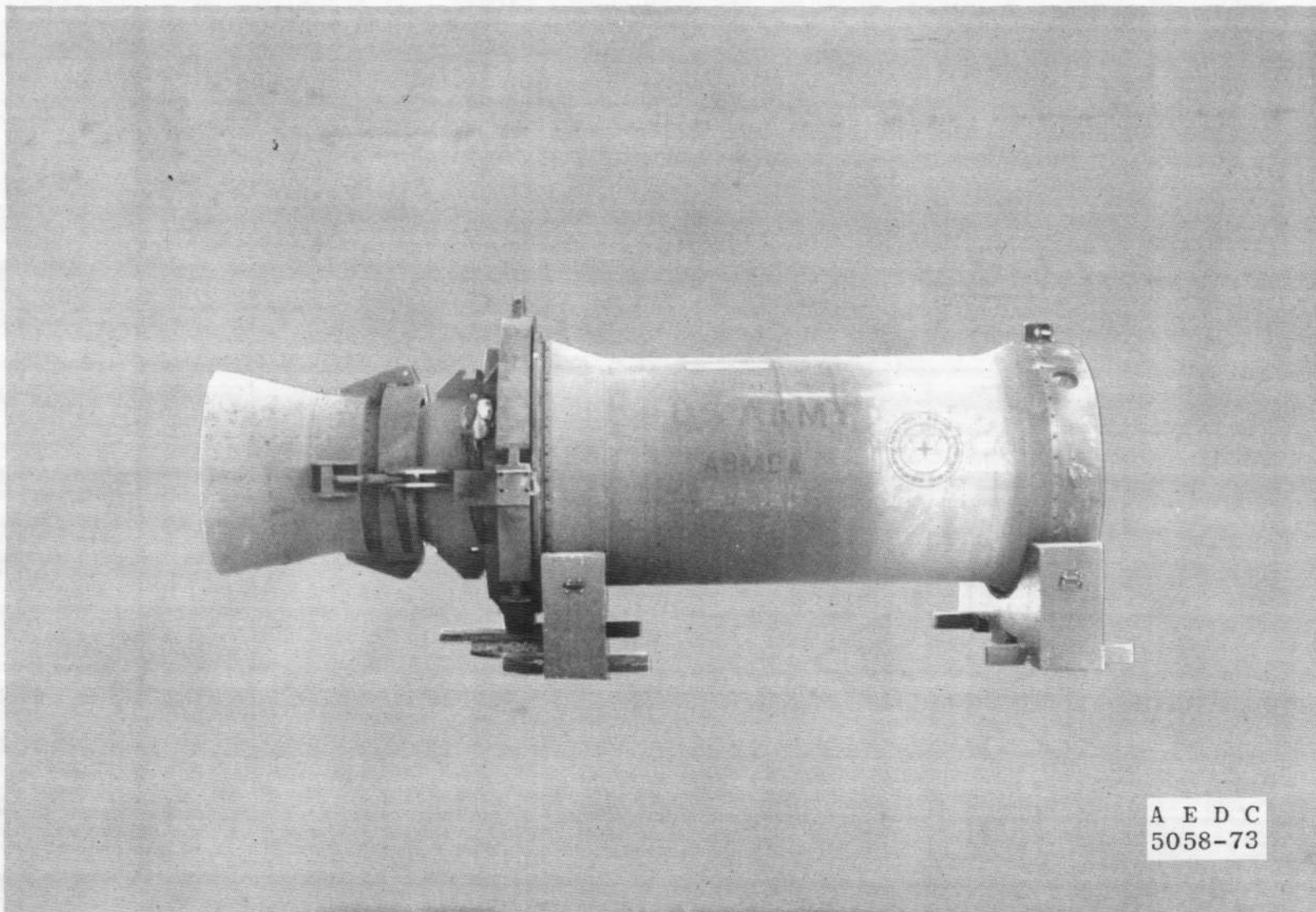
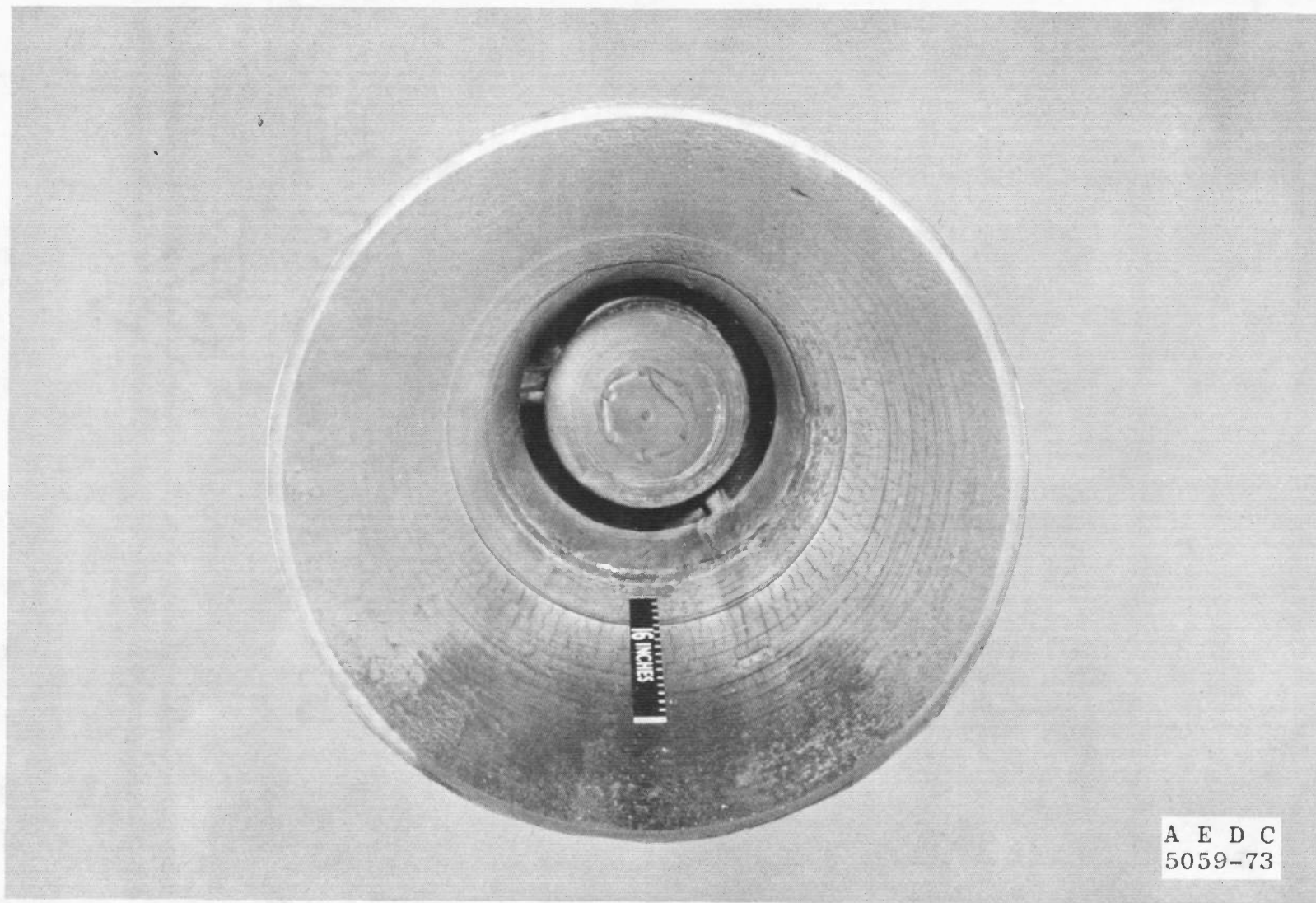


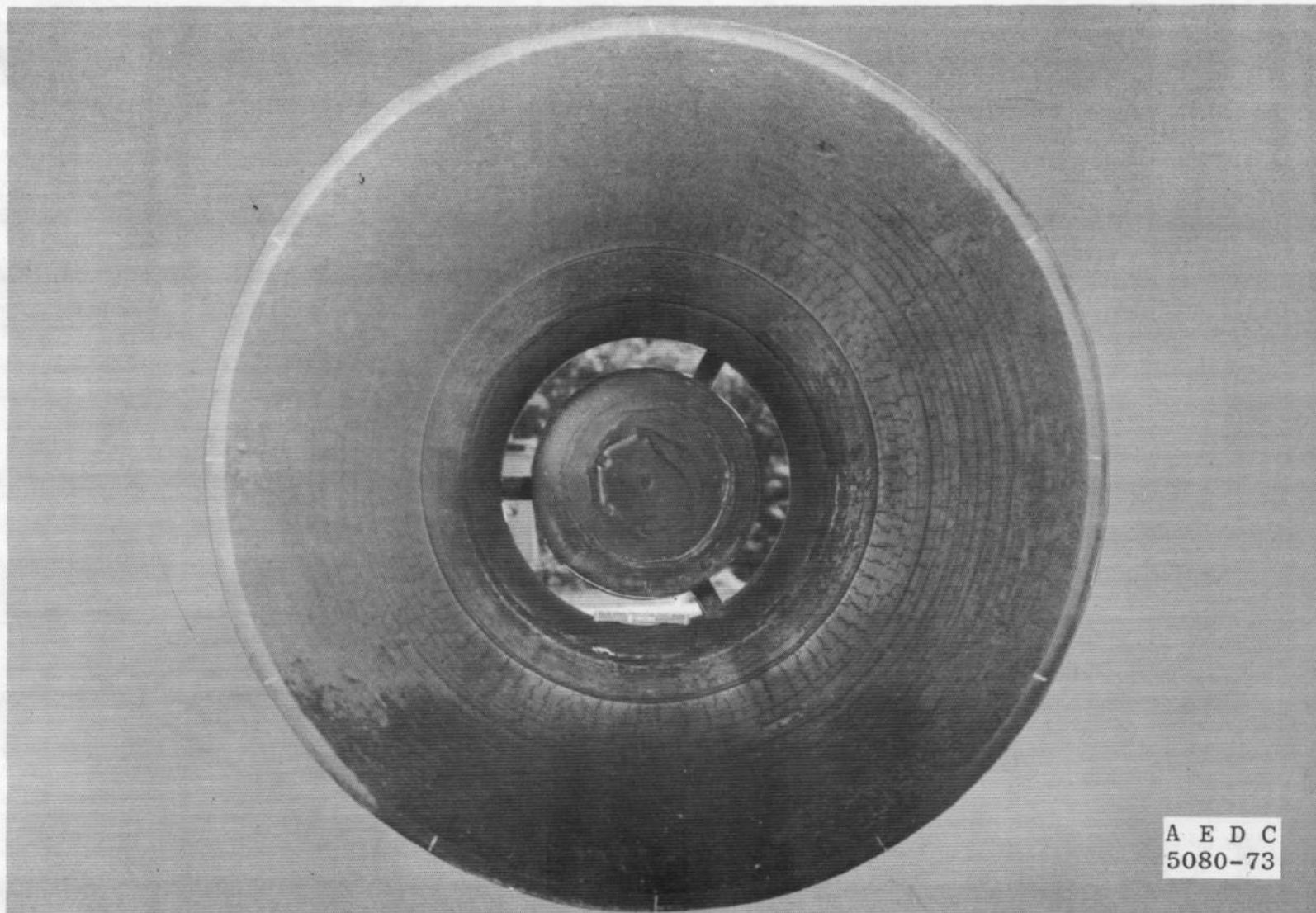
Figure 24. Chamber pressure during extinguishment, fifth firing.



a. Overall view
 Figure 25. Test article postfire.



b. Nozzle end view
Figure 25. Concluded.

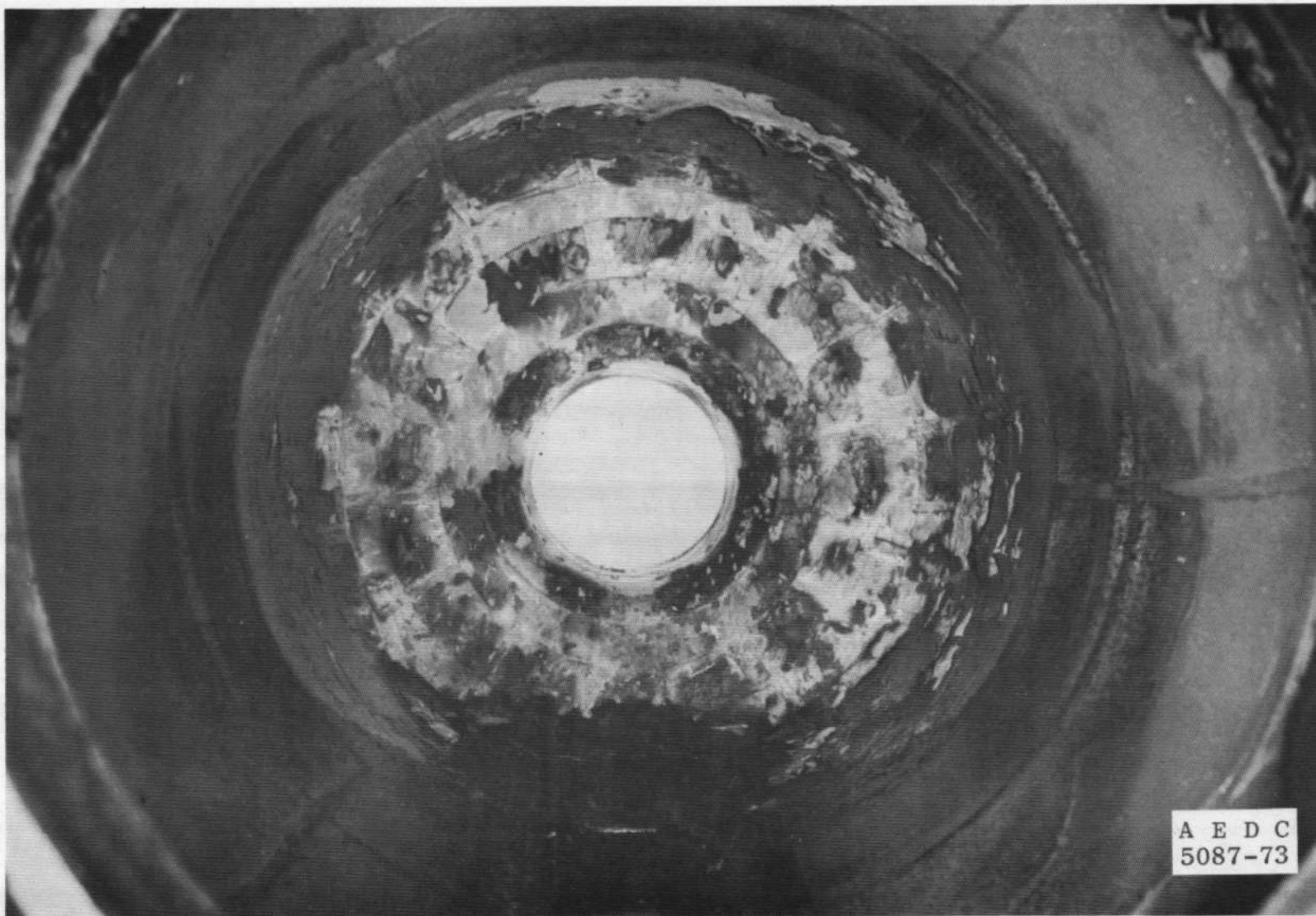


a. Nozzle end view

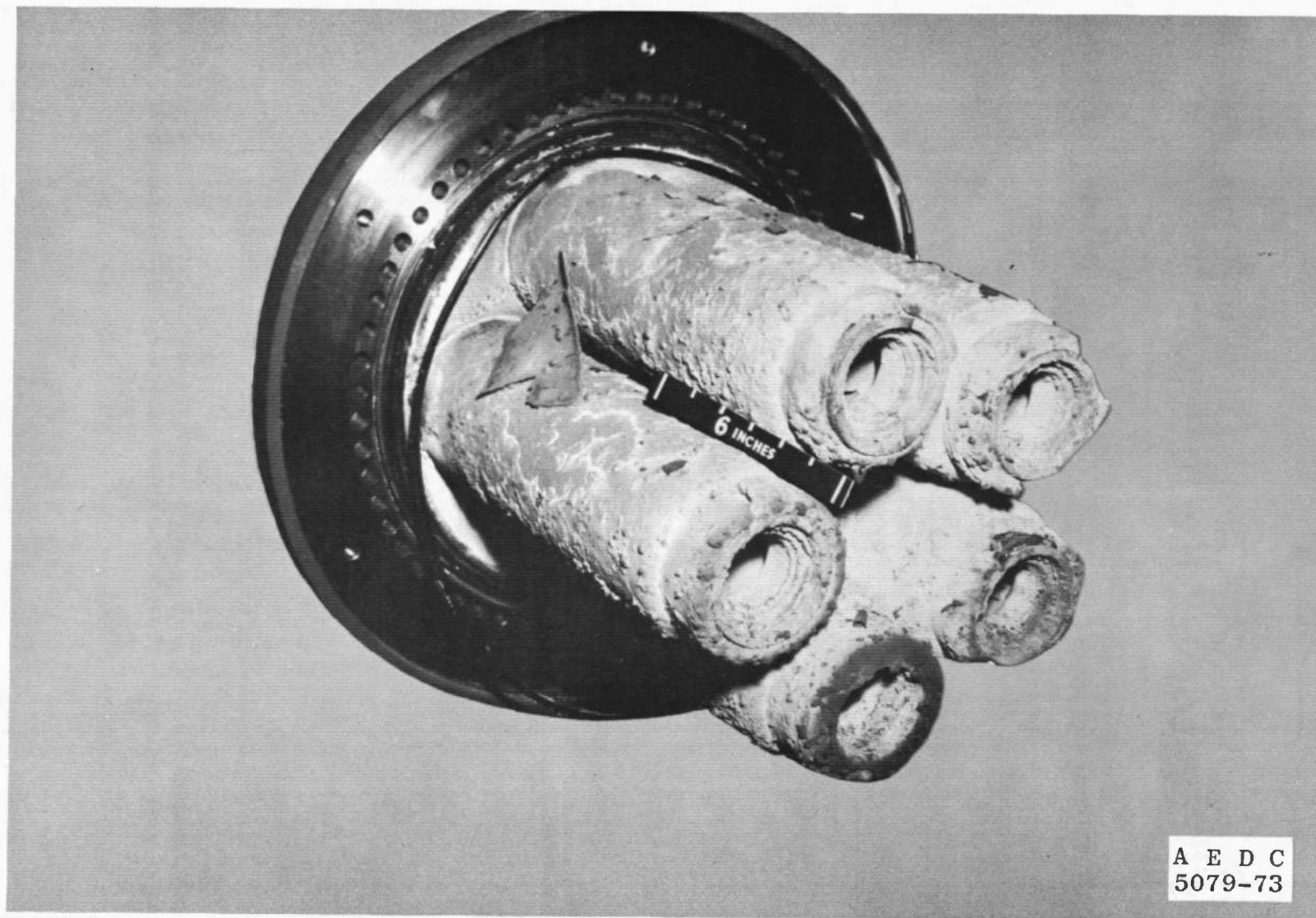
Figure 26. Posttest disassembly.



b. Overall view of pintle
Figure 26. Continued.



c. Motor chamber
Figure 26. Continued.



d. Igniter plate
Figure 26. Concluded.

Table 1. Instrumentation Summary

| PARAMETER SYMBOL | PARAMETER DESCRIPTION | MEASUREMENT RANGE | SENSOR TYPE | SENSOR RANGE | DIGITAL* SYSTEM | ANALOG TAPE | OSCILLO-GRAPH | STRIP CHART |
|------------------|-----------------------|-------------------|---------------|---------------|-----------------|-------------|---------------|-------------|
| ACCELERATION | | G PEAK | | G PEAK | | | | |
| ALGNY | IGNITER ROSS AXIAL | -200 TO 200 | PIEZOELECTRIC | -1K TO 1K | | X | | |
| EVENT-VOLTAGE | | V DC | | | | | | |
| EFS-1 | MAIN MOTOR IGNITION | 0 TO 35 | | | X | X | X | |
| EFS-2 | MAIN MOTOR IGNITION | 0 TO 35 | | | X | | X | |
| EFS-3 | MOTOR IGNITION | 0 TO 35 | | | X | X | X | |
| EFS-4 | MOTOR IGNITION | 0 TO 35 | | | X | | X | |
| EFS-5 | MOTOR IGNITION | 0 TO 35 | | | X | X | X | |
| EFS-6 | MOTOR IGNITION | 0 TO 35 | | | X | | X | |
| EFS-9 | MOTOR IGNITION | 0 TO 35 | | | X | X | X | |
| EFS-10 | MOTOR IGNITION | 0 TO 35 | | | X | X | X | |
| EVENT | | V DC | | | | | | |
| EEC | EXTINGUISHMENT COMM. | 0 TO 28 | | | X | | X | |
| EIA | NOZZLE PINTLE SERVO | - 10 TO 10 | | | X | | X | |
| EILI | INITIAL POS. INTLK | 0 TO 28 | | | X | | X | |
| EP | NOZZLE PINTLE COMM. | - 10 TO 10 | | | X | | X | |
| FPCFB | CHAMBER PRES FEEDBK. | 0 TO 10 | | | X | | X | |
| EPCP | PRES. COMM. PROGRAM. | - 10 TO 10 | | | X | | X | |
| EPPS | PINTLE PROGRAM START | 0 TO 28 | | | X | | X | |
| ERRP-1 | NOZ PINTLE ERROR SIG | - 10 TO 10 | | | X | | X | |
| ERRP-2 | NOZ PINTLE ERROR SIG | - 10 TO 10 | | | X | | X | |
| ETCPS | TRANSFER TO PRESSURE | 0 TO 28 | | | X | | X | |
| FORCE | | LBF | | LBF | | | | |
| FY-1 | AXIAL THRUST | -25000 TO 125000 | STRAIN GAGE | -500K TO 500K | X** | | X | X |
| FY-2 | AXIAL THRUST | -25000 TO 125000 | STRAIN GAGE | -500K TO 500K | X | | X | |
| FY-3 | AXIAL THRUST | -25000 TO 125000 | STRAIN GAGE | -500K TO 500K | X | X | | |
| FY-4 | AXIAL THRUST | -25000 TO 125000 | STRAIN GAGE | -500K TO 500K | | X | | |
| EVENT-CURRENT | | AMPS | | | | | | |
| IFS-1 | MAIN MOTOR IGNITION | 0 TO 10 | | | X | | X | |
| IFS-2 | MAIN MOTOR IGNITION | 0 TO 10 | | | X | | X | |
| IFS-3 | MOTOR IGNITION | 0 TO 10 | | | X | | X | |

Table 1. Concluded

| PARAMETER SYMBOL | PARAMETER DESCRIPTION | MEASUREMENT RANGE | SENSOR TYPE | SENSOR RANGE | DIGITAL* SYSTEM | ANALOG TAPE | OSCILLO-GRAPH | STRIP CHART |
|------------------|-----------------------|-------------------|----------------|--------------|-----------------|-------------|---------------|-------------|
| EVENT-CURRENT | | AMPS | | | | | | |
| IFS-4 | MOTOR IGNITION | 0 TO 10 | | | X | | X | |
| IFS-5 | MOTOR IGNITION | 0 TO 10 | | | X | | X | |
| IFS-6 | MOTOR IGNITION | 0 TO 10 | | | X | | X | |
| IFS-9 | MOTOR IGNITION | 0 TO 20 | | | X | | X | |
| IFS-10 | MOTOR IGNITION | 0 TO 20 | | | X | | X | |
| POSITION | | INCHES | | INCHES | | | | |
| LP | NOZZLE PINTLE | 0 TO 10 | POTENTIOMETRIC | 0 TO 10 | X** | X | X | X |
| PRESSURE | | PSIA | | PSIA | | | | |
| PA-1 | TEST CELL | 0 TO 1 | STRAIN GAGE | 0 TO 1 | X | | X | |
| PA-2 | TEST CELL | 0 TO 1 | STRAIN GAGE | 0 TO 1 | X | | | |
| PA-3 | TEST CELL | 0 TO 5 | STRAIN GAGE | 0 TO 5 | X | | | X |
| PA-5 | TEST CELL | 0 TO 15 | STRAIN GAGE | 0 TO 15 | | X | | |
| PAS-1 | TEST CELL (SPECIAL) | 0 TO 50 | STRAIN GAGE | 0 TO 50 | X | | X | |
| PC-1 | MOTOR CHAMBER | 0 TO 500 | STRAIN GAGE | 0 TO 500 | X** | X | X | |
| PC-2 | MOTOR CHAMBER | 0 TO 500 | STRAIN GAGE | 0 TO 500 | X | X | X | X |
| PC-3 | MOTOR CHAMBER | 0 TO 500 | STRAIN GAGE | 0 TO 500 | X | X | X | |
| PI-1 | MOTOR IGNITER #1 | 0 TO 3000 | STRAIN GAGE | 0 TO 3500 | X | | X | |
| PI-2 | MOTOR IGNITER #2 | 0 TO 3000 | STRAIN GAGE | 0 TO 3500 | X | | X | |
| PI-3 | MOTOR IGNITER #3 | 0 TO 3000 | STRAIN GAGE | 0 TO 3500 | X | | X | |
| PI-4 | MOTOR IGNITER #4 | 0 TO 3000 | STRAIN GAGE | 0 TO 3500 | X | | X | |
| PI-5 | MOTOR IGNITER #5 | 0 TO 3000 | STRAIN GAGE | 0 TO 3500 | X | | X | |
| PPC | PINTLE CAVITY | 0 TO 100 | STRAIN GAGE | 0 TO 100 | X | | | X |
| PPFX | PINTLE HYDR. EXTEND | 0 TO 5000 | STRAIN GAGE | 0 TO 5000 | X | | X | |
| PPRL | PINTLE HYDR. RETRACT | 0 TO 5000 | STRAIN GAGE | 0 TO 5000 | X | | X | |
| PPSY | PINTLE HYDR. SUPPLY | 0 TO 5000 | STRAIN GAGE | 0 TO 5000 | X | | X | X |
| TEMPERATURE | | DEG. F | | DEG. F | | | | |
| TA-1 | AMBIENT TEST CELL | 0 TO 100 | C/A, TYPE K | -300 TO 2500 | | | | X |
| TA-2 | AMBIENT TEST CELL | 0 TO 2500 | C/A, TYPE K | -300 TO 2500 | X | | | |
| TA-5 | AMBIENT TEST CELL | 0 TO 1000 | C/A, TYPE K | -300 TO 2500 | X | | | |
| TP-1 | PROPELLANT GRAIN | 0 TO 100 | C/A, TYPE K | -300 TO 2500 | | | | X |
| TP-2 | PROPELLANT GRAIN | 0 TO 350 | C/A, TYPE K | -300 TO 2500 | X | | | |

*BASIC SAMPLE RATE 200 SAMPLES PER SECOND

**DATA SUPERCOMMUTATED TO 1000 SAMPLES PER SECOND

Table 2. Instrumentation Uncertainties

| <u>INSTRUMENTATION MEASUREMENT</u> | <u>UNCERTAINTY, PERCENT, FULL SCALE</u> |
|--|---|
| Pressure Transducer | ± 0.44 |
| Chromel [®] -Alumel [®] Thermocouple | ± 0.47 |
| Axial-Force Load Cell | ± 0.4 |

Table 3. Motor Temperature

| Date | Temperature, °F | | Location of Motor | Relative Humidity, percent | | Remarks |
|---------|-----------------|-----|------------------------------|----------------------------|-----|--|
| | High | Low | | High | Low | |
| 5/7/73 | 76 | 73 | X-ray Lab ↓ | 50 | 35 | Motor received at X-ray Lab |
| 5/8/73 | 83 | 75 | | 59 | 39 | |
| 5/9/73 | 81 | 75 | | 44 | 42 | |
| 5/10/73 | 76 | 69 | | 42 | 42 | |
| 5/11/73 | 71 | 68 | | 44 | 40 | |
| 5/12/73 | 70 | 69 | | 47 | 45 | |
| 5/13/73 | 69 | 66 | | 45 | 43 | |
| 5/14/73 | 72 | 67 | | 43 | 34 | |
| 5/15/73 | 70 | 66 | | 38 | 31 | |
| 5/16/73 | 74 | 66 | | 36 | 26 | |
| 5/17/73 | 72 | 69 | | 39 | 25 | |
| 5/18/73 | 70 | 69 | | 29 | 28 | |
| 5/18/73 | 79 | 78 | Rocket Preparation Area ↓ | 40 | 30 | Motor moved to Rocket Preparation Area, exposed to 69°F for 50 min |
| 5/19/73 | 79 | 78 | | 62 | 40 | |
| 5/20/73 | 79 | 78 | | 62 | 55 | |
| 5/21/73 | 80 | 77 | | 60 | 44 | |
| 5/22/73 | 79 | 77 | | 66 | 49 | |
| 5/23/73 | 79 | 78 | | 70 | 64 | |
| 5/24/73 | 79 | 78 | | 69 | 62 | |
| 5/25/73 | 79 | 77 | | 67 | 56 | |
| 5/26/73 | 78 | 74 | | 68 | 56 | |
| 5/27/73 | 78 | 76 | | 71 | 66 | |
| 5/28/73 | 75 | 74 | | 65 | 61 | |
| 5/29/73 | 76 | 74 | | 63 | 59 | |
| 5/30/73 | 75 | 74 | | 64 | 59 | |
| 5/31/73 | 75 | 74 | | 63 | 53 | |
| 6/1/73 | 75 | 74 | | 67 | 51 | |
| 6/2/73 | 76 | 74 | | 70 | 54 | |
| 6/3/73 | 76 | 74 | | 70 | 59 | |
| 6/4/73 | 74 | 72 | | 70 | 60 | |
| 6/5/73 | 75 | 74 | | 70 | 60 | |
| 6/6/73 | 75 | 74 | | 70 | 59 | |
| 6/7/73 | 75 | 74 | | 70 | 58 | |
| 6/8/73 | 75 | 72 | | 70 | 64 | |
| 6/9/73 | 74 | 72 | | 69 | 64 | |
| 6/10/73 | 74 | 72 | | 69 | 64 | |
| 6/11/73 | 74 | 74 | | 69 | 66 | |
| 6/12/73 | 75 | 72 | | 70 | 60 | |

Table 3. Concluded


| Date | Temperature, °F | | Location of Motor | Relative Humidity, percent | | Remarks |
|---------|-----------------|-----|--|----------------------------|-----|--|
| | High | Low | | High | Low | |
| 6/13/73 | 73 | 73 | Rocket Preparation Area  | 60 | 59 | |
| 6/14/73 | 73 | 72 | | 59 | 54 | |
| 6/15/73 | 73 | 72 | | | | |
| 6/16/73 | 72 | 70 | | | | |
| 6/17/73 | 71 | 70 | | 64 | 59 | |
| 6/18/73 | 72 | 70 | | | | |
| 6/19/73 | | | | | | |
| 6/19/73 | 71 | 71 | | | | |
| 6/20/73 | 71 | 67 | | 66 | 59 | Motor moved to test cell, exposed to 81°F for 1 hr |
| 6/21/73 | 71 | 69 | | 62 | 60 | |
| 6/22/73 | 74 | 70 | Test Cell | 62 | 60 | Motor fired at 2205 hours |
| 6/23/73 | 74 | 72 | | | | |
| 6/24/73 | 74 | 70 | | | | |
| 6/25/73 | 73 | 69 | | | | |

Table 4. Nozzle Measurements

| <u>Location, deg</u> | <u>Prefire Throat Annular Gap*, in.</u> | <u>Prefire Exit, in.</u> | <u>Postfire Exit, in.</u> |
|------------------------|---|--------------------------|---------------------------|
| 0 | 1.963 | 39.889 | 39.908 |
| 30 | | 39.885 | 39.872 |
| 60 | | 39.912 | 39.839 |
| 90 | 2.060 | 39.984 | 39.868 |
| 120 | | 39.908 | 39.880 |
| 150 | | 39.917 | 39.901 |
| 180 | 2.000 | | |
| 270 | 1.917 | | |
| Average, in. | | 39.916 | 39.878 |
| Area, sq in. | | 1251.36 | 1248.98 |
| Percent Change in Area | | | -0.2 |

*Nozzle pintle in fully extended position

Table 5. Summary of Motor Performance

General Information

| | |
|--|----------|
| Motor Designation | CSRM-4 |
| Date Cast | 3-23-73 |
| Date Fired | 6-25-73 |
| Gross Motor Weight, lbm | 13,387 |
| Manufacturer's Stated Propellant Weight, lbm | 5,950 |
| Prefire Nozzle Exit Area, sq in. | 1251.364 |
| Prefire Motor Temperature, deg F. | 69 |

Altitude

| | |
|----------------------------------|--------|
| First Firing | |
| at Ignition, ft | 88,000 |
| Average until Extinguishment, ft | 72,000 |
| Second Firing | |
| at Ignition, ft | 89,000 |
| Average until Extinguishment, ft | 71,000 |
| Third Firing | |
| at Ignition, ft | 89,000 |
| Average until Extinguishment, ft | 76,000 |
| Fourth Firing | |
| at Ignition, ft | 89,000 |
| Average until Extinguishment, ft | 78,000 |
| Fifth Firing | |
| at Ignition, ft | 89,000 |
| Average until Extinguishment, ft | 76,000 |

Time

| | |
|--------------------------------|-----------|
| First Firing | |
| Ignition, sec | T-0 |
| Transfer to Pressure Mode, sec | T+0.160 |
| Extinguishment Command, sec | T+5.175 |
| Extinguishment, sec | T+5.78 |
| Second Firing | |
| Ignition, sec | T+65.145 |
| Transfer to Pressure Mode, sec | T+65.275 |
| Extinguishment Command, sec | T+70.285 |
| Extinguishment, sec | T+70.86 |
| Third Firing | |
| Ignition, sec | T+130.245 |
| Transfer to Pressure Mode, sec | T+130.385 |
| Extinguishment Command, sec | T+135.425 |
| Extinguishment, sec | T+135.85 |

Table 5. Continued

Time (Cont'd)

| | |
|--------------------------------|-----------|
| Fourth Firing | |
| Ignition, sec | T+195.360 |
| Transfer to Pressure Mode, sec | T+195.505 |
| Extinguishment Command, sec | T+200.520 |
| Extinguishment, sec | T+201.05 |
| Fifth Firing | |
| Ignition, sec | T+260.480 |
| Transfer to Pressure Mode, sec | T+260.625 |
| Extinguishment Command, sec | T+265.645 |
| Extinguishment, sec | T+266.12 |

Chamber Pressure

| | |
|----------------------|-----|
| First Firing | |
| High-Pressure Step | |
| Average, psia | 335 |
| Low-Pressure Step | |
| Average, psia | 147 |
| Extinguishment, psia | 36 |
| Second Firing | |
| High-Pressure Step | |
| Average, psia | 402 |
| Low-Pressure Step | |
| Average, psia | 153 |
| Extinguishment, psia | 26 |
| Third Firing | |
| High-Pressure Step | |
| Average, psia | 274 |
| Low-Pressure Step | |
| Average, psia | 136 |
| Extinguishment, psia | 32 |
| Fourth Firing | |
| High-Pressure Step | |
| Average, psia | 224 |
| Low-Pressure Step | |
| Average, psia | 127 |
| Extinguishment, psia | 30 |
| Fifth Firing | |
| High-Pressure Step | |
| Average, psia | 277 |
| Low-Pressure Step | |
| Average, psia | 127 |
| Extinguishment, psia | 26 |

Table 5. Concluded

Axial Force

| | |
|---------------------------|--------|
| First Firing | |
| High-Pressure Step | |
| Average Measured, lbf | 71,100 |
| Average Vacuum, lbf | 71,800 |
| Low-Pressure Step | |
| Average Measured, lbf | 38,300 |
| Average Vacuum, lbf | 39,000 |
| Second Firing | |
| High-Pressure Step | |
| Average Measured, lbf | 79,700 |
| Average Vacuum, lbf | 80,500 |
| Low-Pressure Step | |
| Average Measured, lbf | 36,900 |
| Average Vacuum, lbf | 37,700 |
| Third Firing | |
| High-Pressure Step | |
| Average Measured, lbf | 53,400 |
| Average Vacuum, lbf | 54,000 |
| Low-Pressure Step | |
| Average Measured, lbf | 30,200 |
| Average Vacuum, lbf | 30,800 |
| Fourth Firing | |
| High-Pressure Step | |
| Average Measured, lbf | 42,000 |
| Average Vacuum, lbf | 42,600 |
| Low-Pressure Step | |
| Average Measured, lbf | 28,000 |
| Average Vacuum, lbf | 28,600 |
| Fifth Firing | |
| High-Pressure Step | |
| Average Measured, lbf | 52,500 |
| Average Vacuum, lbf | 53,100 |
| Low-Pressure Step | |
| Average Measured, lbf | 31,800 |
| Average Vacuum, lbf | 32,500 |

APPENDIX A CALIBRATION

Axial-Force System

The axial-force load cell was physically calibrated in the calibration laboratory before installation in the test cell force-measuring system by direct application of loads traceable to the National Bureau of Standards (NBS). The instrumentation recording systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions using a resistance shunting method to simulate load cell output.

Pressure Transducers

The pressure transducers were physically calibrated in the AEDC calibration laboratory before installation by direct application of pressure loads traceable to the NBS. The instrumentation recording systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions using a resistance shunting method to simulate pressure transducer output.

Temperatures

The thermocouples were fabricated from standard thermocouple wire, the electromotive force output of which is traceable to the NBS through the wire manufacturer. The thermocouples were connected directly to a 150°F reference temperature junction, and the NBS standard temperature/voltage relationships were used for conversions to engineering units. The temperature instrumentation systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions by the voltage substitution method which simulated a known input signal.

Position Potentiometer

Nozzle pintle position potentiometer feedback voltage as a function of measured pintle position was determined at AEDC. This relationship was not linear, and intermediate points between the fully retracted and the fully extended positions were determined.

APPENDIX B METHODS OF CALCULATION

1. PALT = Average test cell pressure, psia

$$PALT = (PA-1 + PA-2)/2$$

2. PCA = Average chamber pressure, psia

$$PCA = (PC-1 + PC-2)/2$$

3. FA = Average axial force, lbf

$$FA = (FY-1 + FY-2)/2$$

4. FAVAC = Vacuum axial thrust, lbf

$$FAVAC = FA + PALT (AE)$$

where AE = Prefire nozzle exit area measured at AEDC

5. FPE = Pintle ejection force, lbf

$$FPE = 26.97 (PPRE) - 28.87 (PPEX)$$

6. RFPPC = Pintle ejection force to average chamber pressure ratio, lbf/psia

$$RFPPC = FPE/PCA$$

7. RFYPC = Vacuum axial thrust to average chamber pressure ratio, lbf/psia

$$RFYPC = FAVAC/PCA$$